Environment and Climate Change Canada
Environnement et Changement climatique Canada

The Arctic Observing Mission (AOM):
a Canadian-led mission concept for quasi-geostationary observations of the North

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*Environment and Climate Change Canada (ECCC)
*Canadian Space Agency (CSA)

NOAA System performance Assessment Team (SAT) briefing
2023 April 3

Canada

Outline

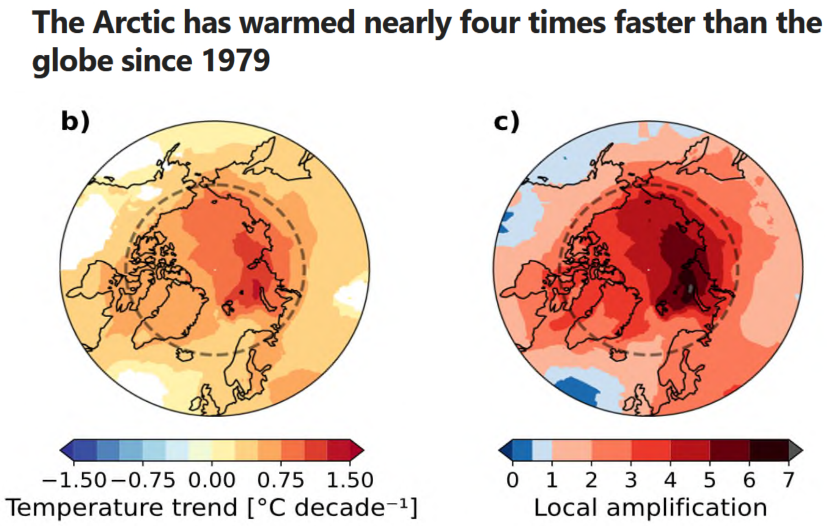
- **Introduction**: Arctic, orbits, AOM: history, overview, schedule

- Meteorology
- Space Weather
- Air Quality
- **Greenhouse Gases**

- **Conclusions, Next Steps and Partnerships**

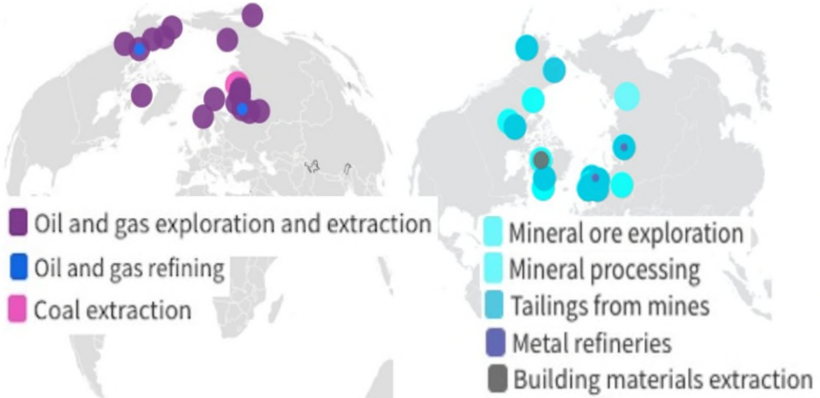
The Changing Arctic

Weather & Climate



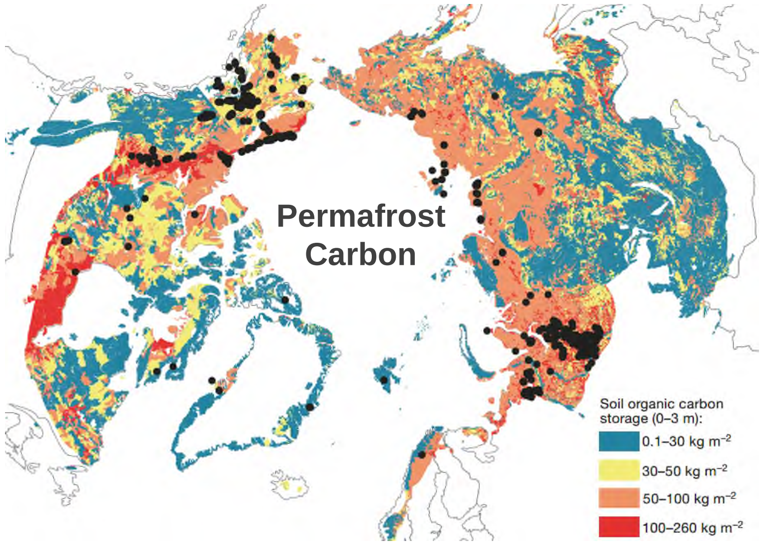
Rantanen et al. 2022, Nature

Resource Extraction



Hanaček et al. 2022, Ecological Economics

Climate Feedbacks

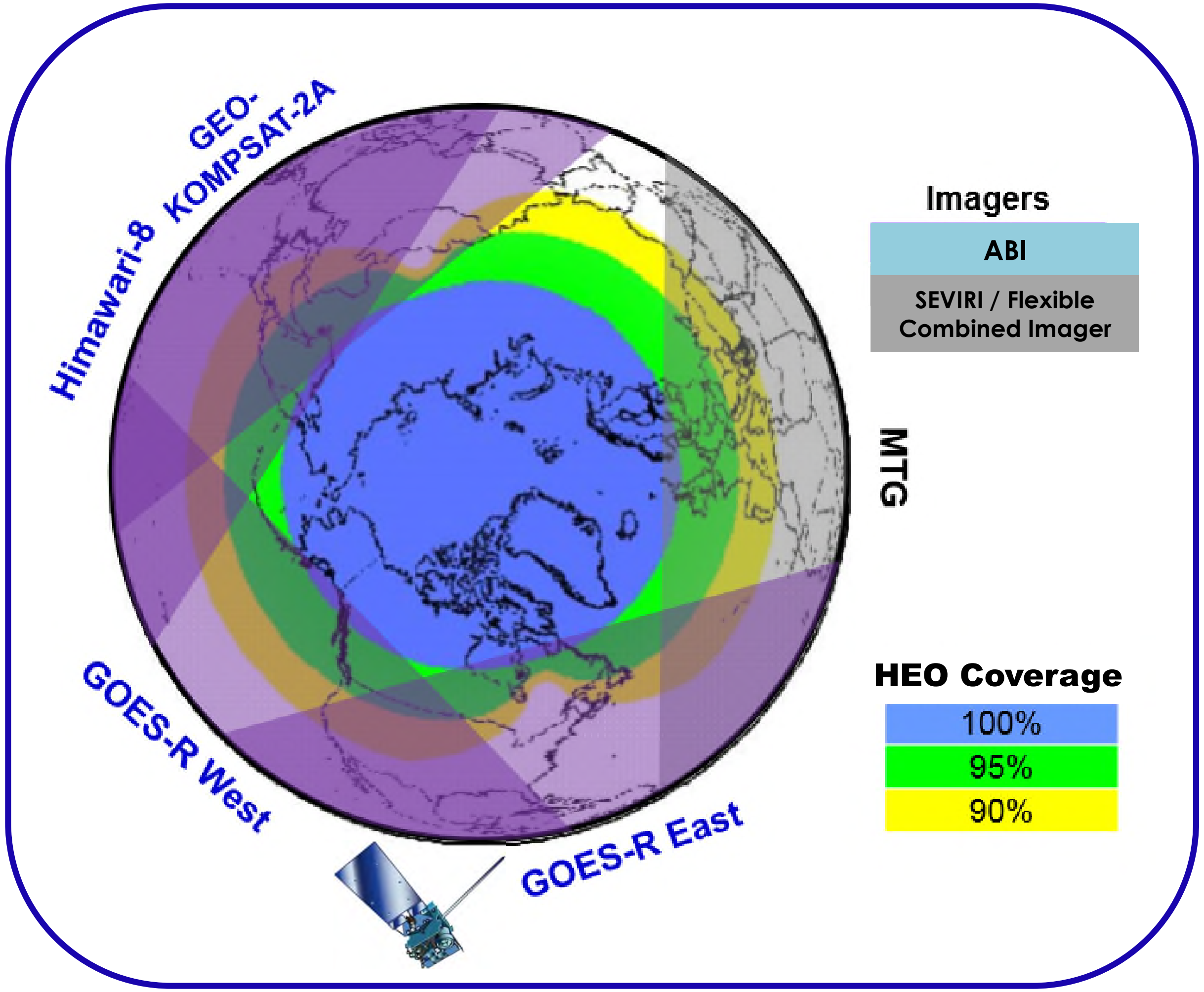


Schuur et al. 2015, Nature

- Arctic temperatures have increased 3-4 times global average and this trend is expected to continue
- Temperature changes are linked to linked to other changes in the Arctic system (ice, stratospheric ozone, permafrost, etc.) and more severe change is expected in the future
- Anthropogenic activity in the North is increasing (e.g. resource extraction)
- Permafrost holds ~1600 PgC (almost twice atmospheric mass) and estimates suggest release of ~5-15% as CO_2 or CH_4 by 2100

There is a need for improved satellite observations over the North

Meteorology has used LEO and GEO satellites together for decades and modern weather prediction relies on this. Air Quality is now increasing use of GEO (e.g. NASA's TEMPO) and GHGs should follow.



Low Earth Orbit (LEO) satellites give global coverage but with low temporal revisit rates

Geostationary Orbit (GEO) gives rapid revisit, but satellite coverage is limited to ~60ºS-60ºN due to viewing geometry from equatorial orbit

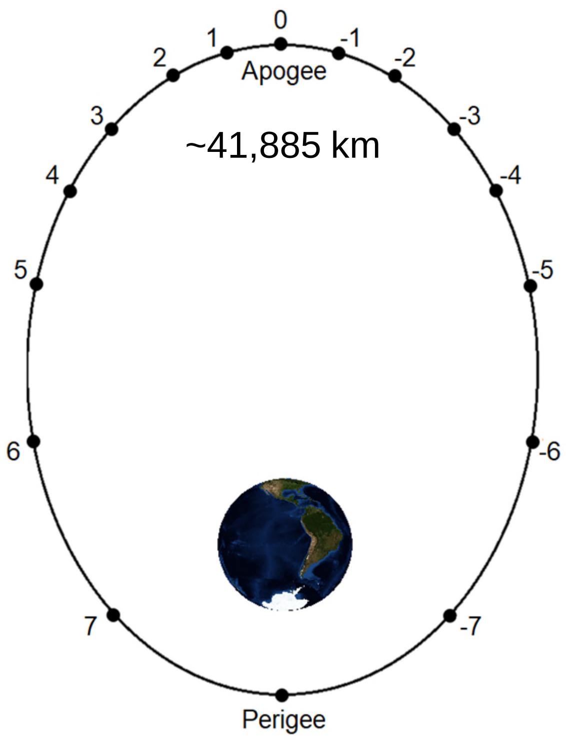
A **Highly Elliptical Orbit (HEO)** can address the spatial/temporal gap over the North

Figure Credit: L3Harris

Highly Elliptical Orbit (HEO)

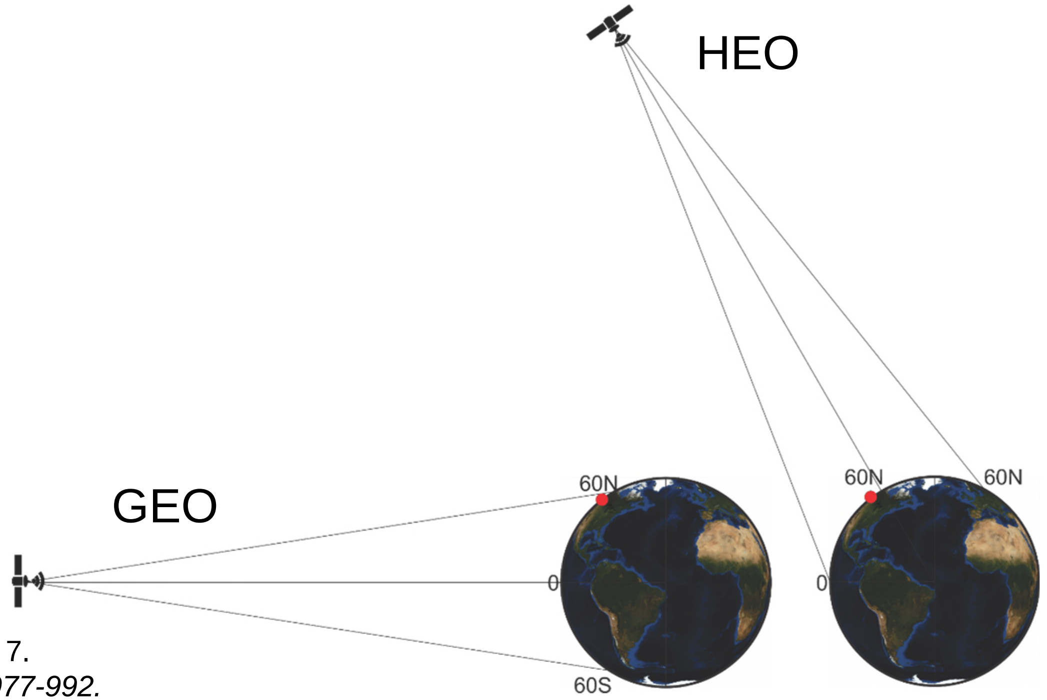
- Highly elliptical orbits can be used for quasi-geostationary high latitude Earth observations
- Multiple Canadian-led studies into HEO orbit variations. Example:

a) 16-hour elliptical orbit



b) Three apogee (TAP) orbit ground track

c) Viewing angle from HEO (i = 63.435º)



Kidder and von der Haar (1990), J. Atm. Ocean Tech., 7.
Trishchenko and Garand (2011), *J. Atm. Ocean Tech., 28, 977-992.*
Trishchenko, Garand, Trichtchenko (2011), *J. Atm. Ocean Tech., 28, 1407-1422.*
Trichtchenko, Nikitina, Trishchenko, Garand (2014), *Adv. Space. Res. 54, 2398-2414.*
Garand, Trishchenko, Trichtchenko, Nassar (2014), *Physics in Canada*, 70, 4, 247-254.
Trishchenko, Garand, Trichtchenko, Nikitina (2016), *BAMS*, 19-24.
Trishchenko, Trichtchenko, Garand (2019), *Adv. Space. Res. 63, 12, 3761-3767.*

Brief History of Canadian HEO Activities

- **Polar Communications and Weather (PCW)** mission was a HEO concept for Arctic communications and meteorology under consideration from ~2007-2012, with enhancements considered under the **Polar Highly Elliptical Orbit Science (PHEOS)** program
- The **Weather, Climate and Air quality (WCA)** instrument suite was a small (~50-85 kg) atmospheric enhancement consisting of a TIR to SWIR Imaging Fourier Transform Spectrometer (IFTS) and a UV-Vis grating Spectrometer (UVS), completed Phase A in 2012
- Mission concept feasibility study and technology development studies involving ECCC, CSA and industry contractors (2015-2018) led to the **Atmospheric Imaging Mission for Northern Regions (AIM-North)**, https://doi.org/10.1080/07038992.2019.1643707, PI: Ray Nassar
- AIM-North began Phase 0 in late 2018, but strong interest from Meteorological Service of Canada (MSC) led to an expansion of AIM-North's scope to include meteorology and space weather via a possible Canadian-led international partnership, called the **Arctic Observing Mission (AOM)**
- AOM now in "Pre-formulation study", if funded, will launch ~2034 for a 10-year mission

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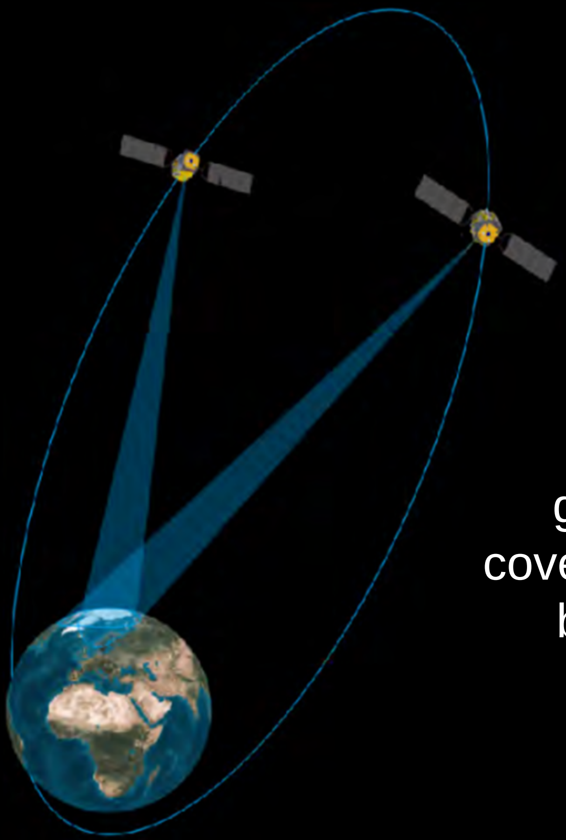
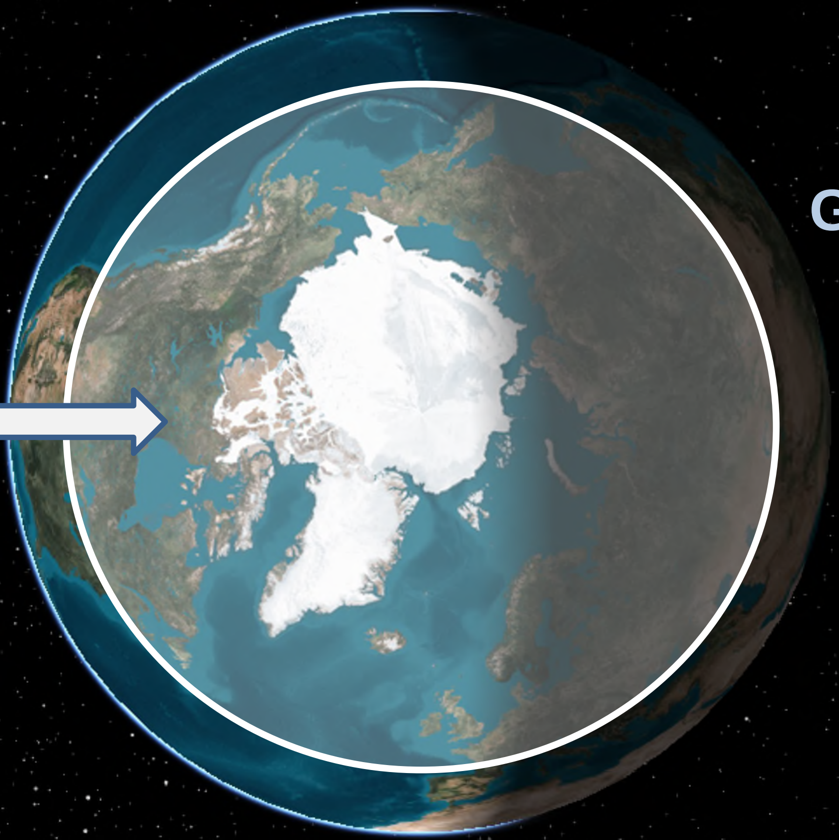
The Arctic Observing Mission (AOM)

A Canadian-led international mission concept



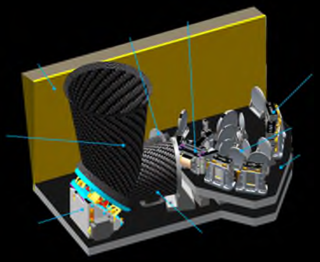
Two satellites in a Highly Elliptical Orbit

AOM quasi-geostationary coverage of Arctic & boreal region (~45-90°N)

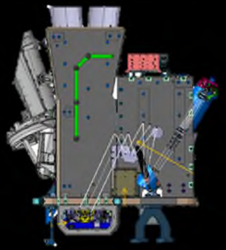


Meteorology

Greenhouse Gases



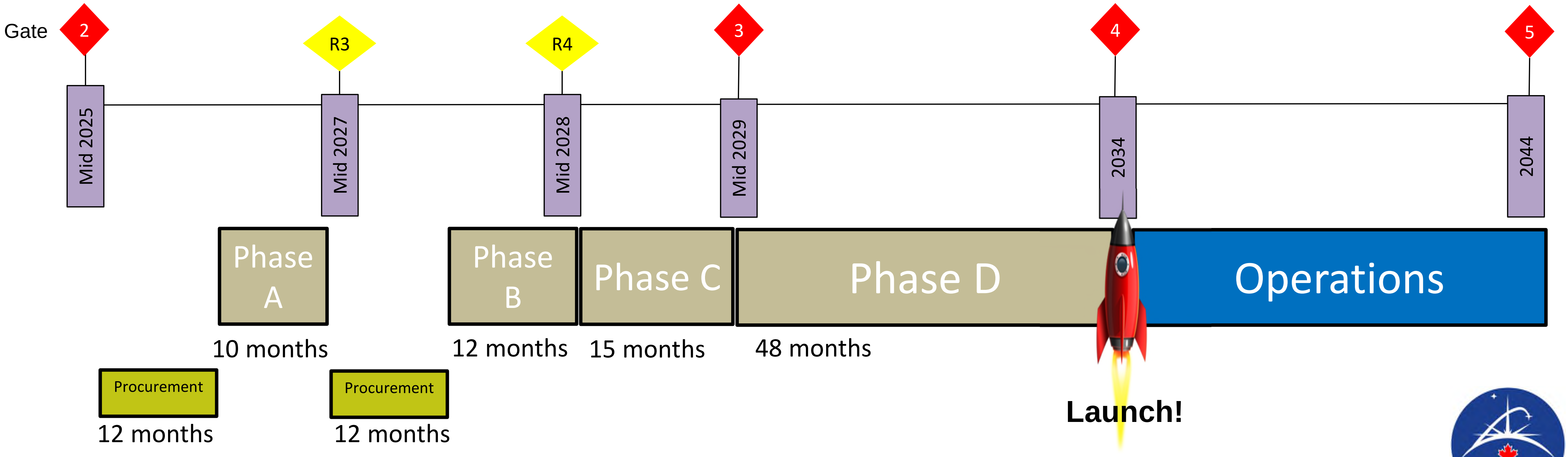
Air Quality



Space Weather

AOM Project Status & Schedule

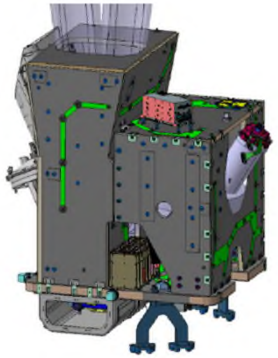
- Currently in Pre-Formulation Study (Phase 0): RFP for ~18-month $2.5M CAD industry contract (closes April 6) with interest from ABB, MDA, Airbus, L3Harris, Lockheed-Martin, Raytheon.
- Contract will refine the mission/instrument concepts and provide updated cost estimates.
- Aiming to proceed with budget request in late 2024 with expected funding decision in spring 2025.
- If successful, implementation will begin, aim for launch in 2034 and 10-year mission lifetime.



Proposed Arctic Observing Mission (AOM) Payloads

UV-Vis Air Quality Spectrometer

~100 kg



Meteorological Imager

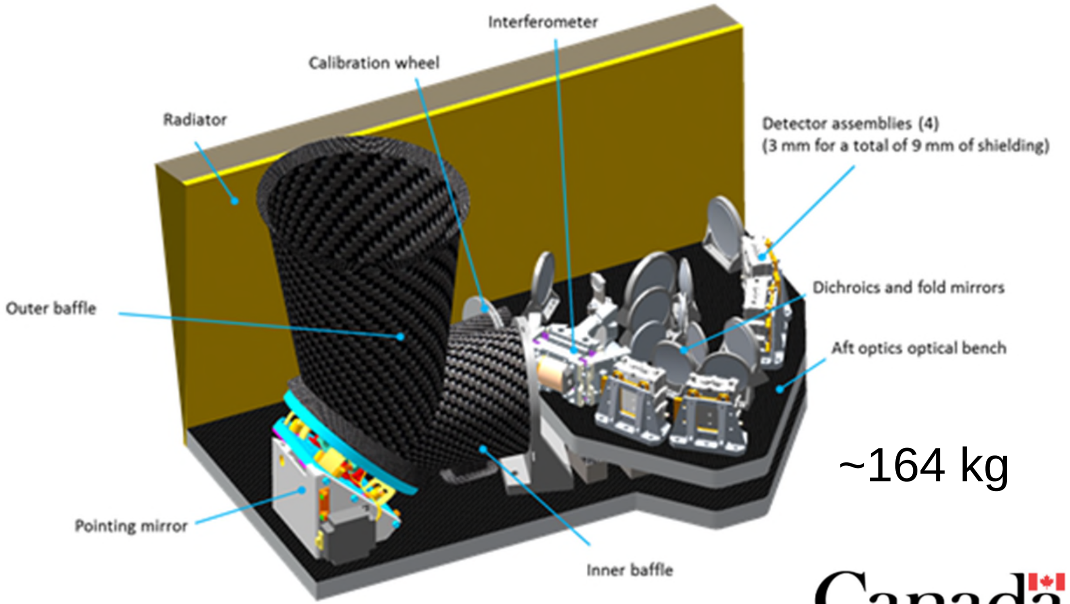
Advanced Baseline Imager (ABI)
NOAA spare expected to be contributed to AOM

~350 kg

NIR-SWIR GHG Imaging Fourier Transform Spectrometer (IFTS)

Bands: 0.76, 1.6, 2.1, 2.34 μm.

Hourly ~4x4 km^2 CO_2, CH_4, CO and Solar Induced Fluorescence (SIF) over cloud-free, Arctic & Boreal land during daylight.

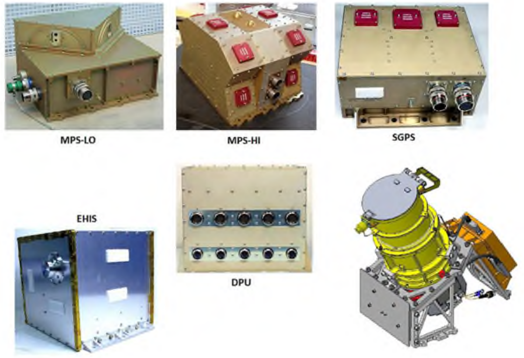


~164 kg

Canada

Space weather instrument suite

~95 kg



EUMETSAT

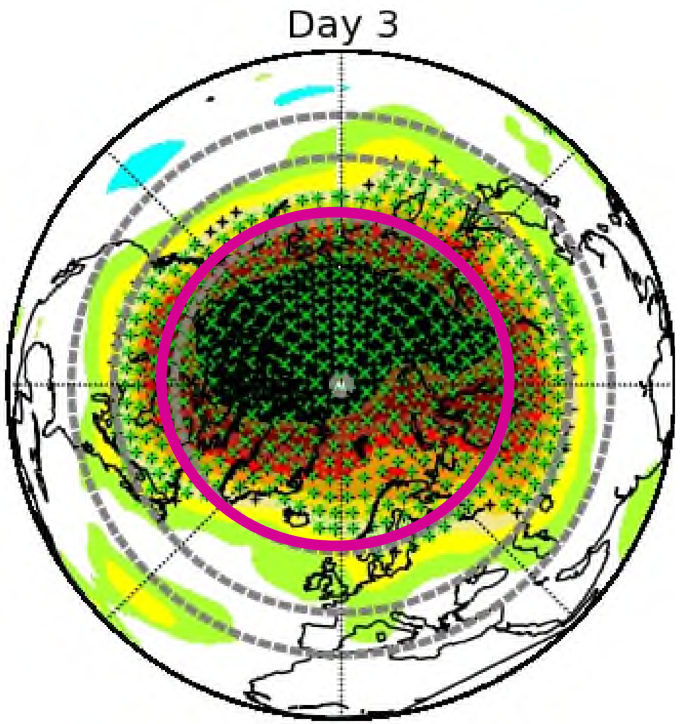
Contributions in data reception & data processing

Arctic Observing Mission (AOM)

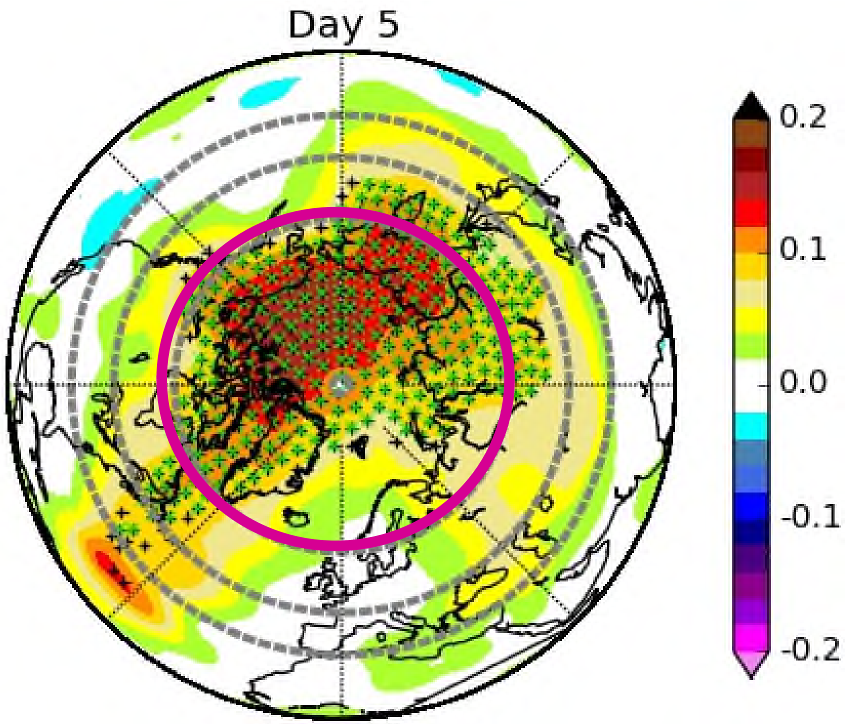
- Meteorology
- Space Weather
- Air Quality
- Greenhouse Gases

Potential Benefits of HEO Observations in Numerical Weather Prediction

Impact of all assimilated satellite data between 60-90ºN on global NWP



- Positive impact maximum within the area of interest (pink circle) but expanding throughout most of Southern Canada, especially in the East
- The signal decreases with time which suggests that HEO data would have the strongest impact on short-term forecast (0-72 hrs)



* indicates 95% confidence interval

Study by Stéphane Laroche and Émmanuel Poan

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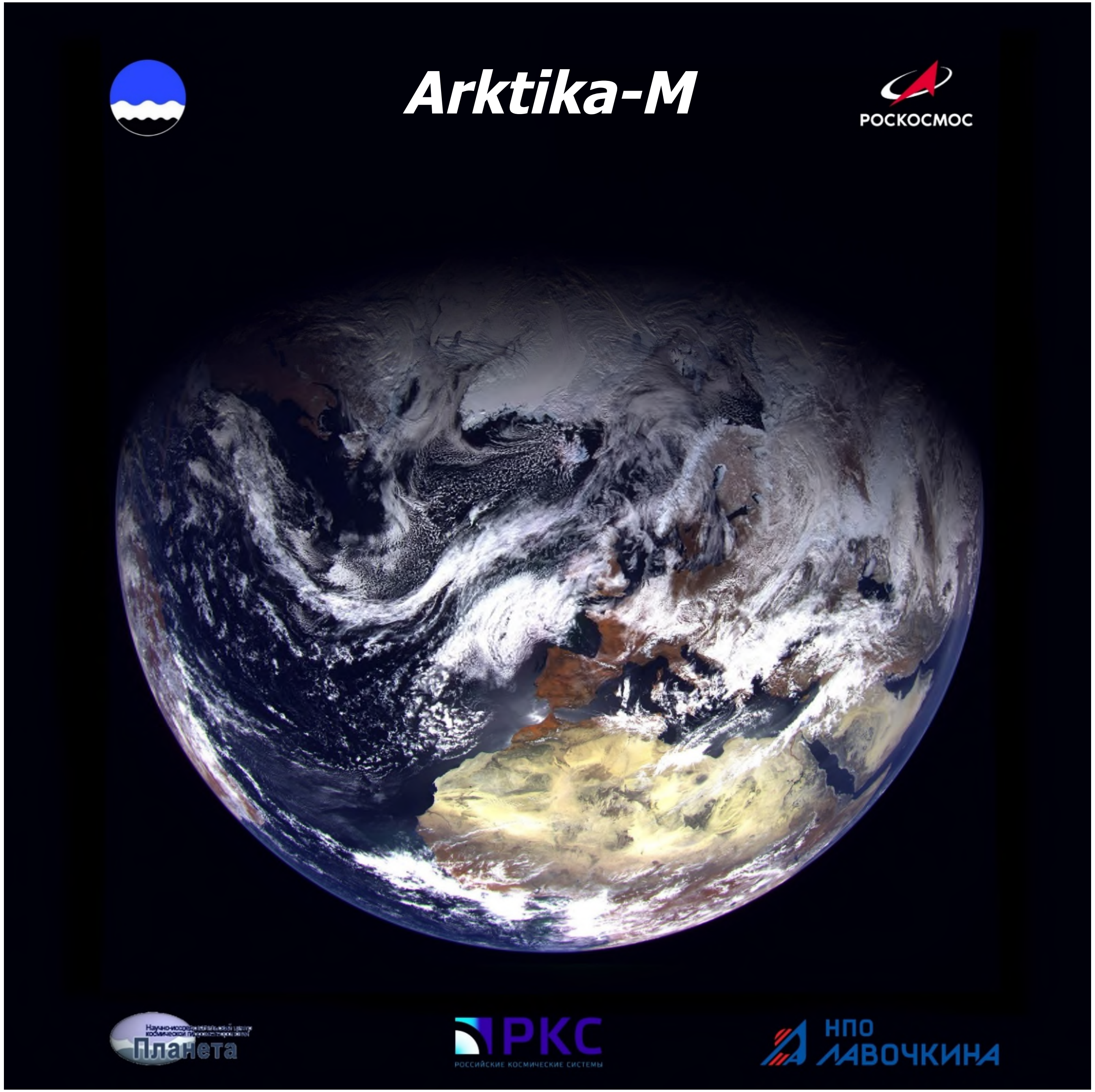


Arktika-M

- Russia has pioneered HEO for communications and military satellites with ‘Molniya’ (Lightning) Orbits.
- Canada, US, Europe and Russia have all considered meteorological satellites in HEO since at least 2007 and they have been recommended by the World Meteorological Organization (WMO).
- HEO had not been used for Earth Observation / Remote Sensing until Russia’s first Arktika-M satellite was launched on February 28, 2021.
- Arktika-M includes Russia’s Elecktro-L (10-channel) meteorological imager and space weather instruments.

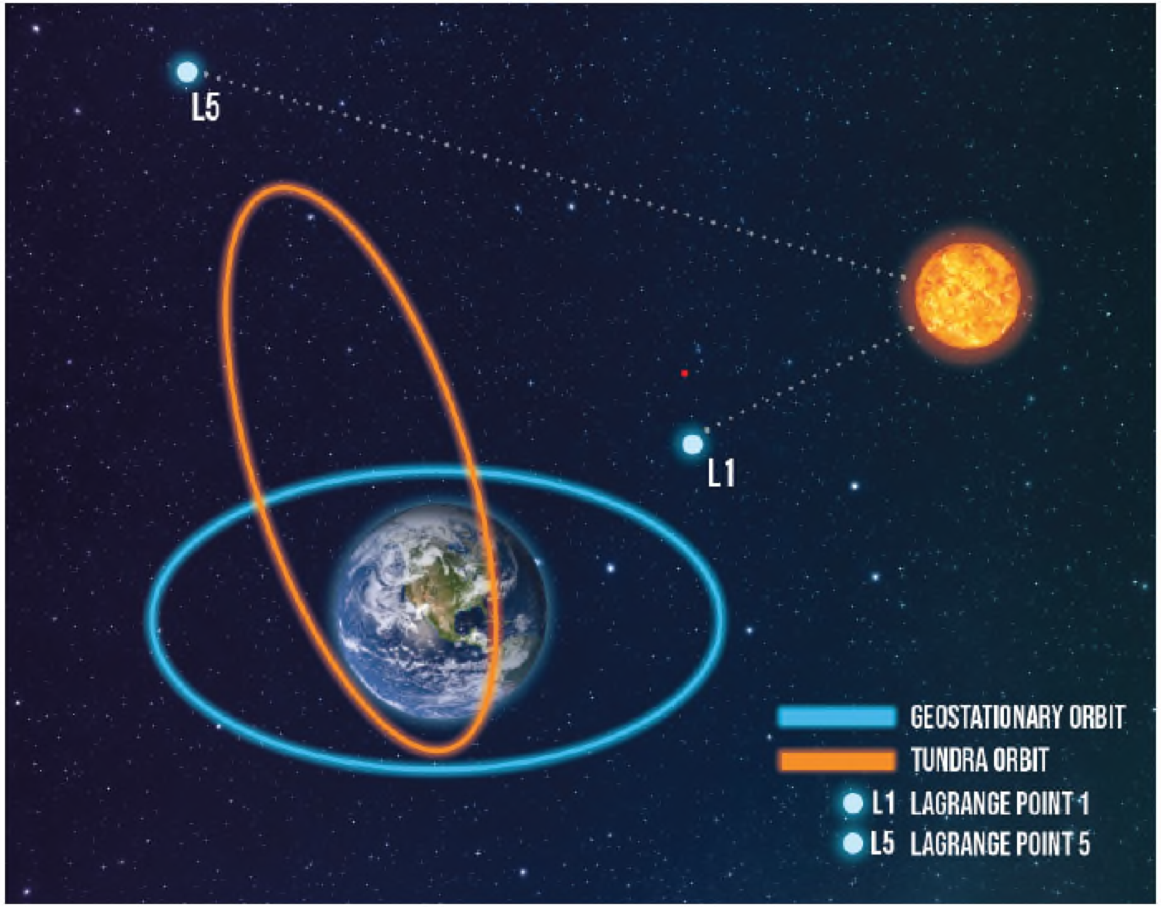
NOAA SATELLITE AND INFORMATION SERVICE | GOES-R SERIES PROGRAM OFFICE

Geostationary and Extended Orbits (GEO-XO)

FACT SHEET

What is GEO-XO?

The Geostationary and Extended Orbits (GEO-XO) program is planning the mission that will follow NOAA's Geostationary Operational Environmental Satellite – R (GOES-R) Series and Space Weather Follow-On (SWFO) programs. GEO-XO will provide continuity of Earth observations from geostationary orbit and is planning for future space weather capabilities from the sun-Earth Lagrange point 1 (L1) and beyond. Other orbits, such as a highly elliptical "tundra" orbit to provide arctic coverage are also being considered. Program scope, structure, and observational capabilities are currently being defined.



GeoXO is now Geostationary Extended *Observations*

Advanced Baseline Imager (ABI)

- ABI is the meteorological imager developed by L3Harris for the Geostationary Operational Environmental Satellite R (GOES-R) program
- ABI supports forecasts, numerical weather prediction (NWP) and yields numerous Level 2 products for a wide range of applications
- Japan’s Advanced Himawari Imager (AHI) and South Korea’s Advanced Meteorological Imager (AMI) are slightly-modified versions of the ABI also currently operating in GEO

- GOES-16, -17, -18 launched in 2016, 2018, 2022
- GOES-U is scheduled for launch in April 2024

- *ABI Flight Model 5 is a spare instrument that could be available for AOM if it is not needed for GOES-R program*

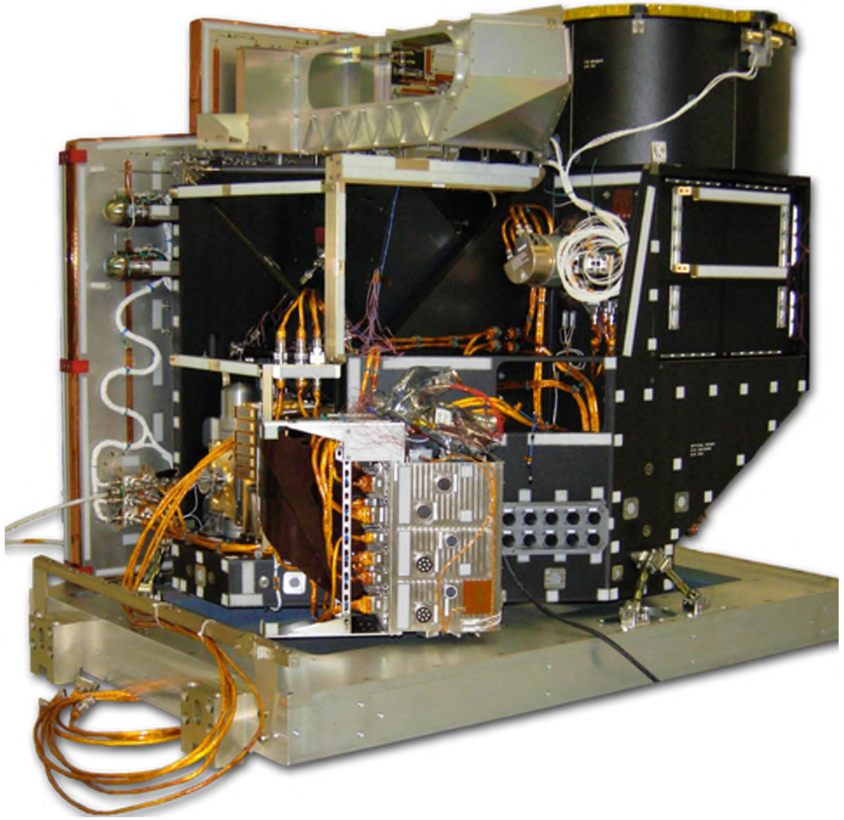
~350 kg, 16 channels

Schmidt et al. (2017), A Closer Look at the ABI on the GOES-R series, Bulletin of the American Meteorological Society, doi:10.1175/BAMS-D-15-00230.1

https://www.goes-r.gov/

L3HARRIS™ ABI to HEO Study

- NOAA funded an L3Harris study on adapting the ABI to operate in HEO, which was completed in December 2022.
- Concluded that ABI hardware can operate from TAP (16 h) or Tundra (24 h) orbit, however software modifications related to scanning, pointing, onboard calibration and the overall concept of operations are needed.
- These software and conops changes all seem feasible, but specific adaptations require more-focused studies.
- Related CSA analyses indicate that ABI lifetime in different HEO radiation environments also requires further study. Current understanding suggests that TAP or Tundra are both feasible, although degree of required shielding varies.



Arctic Observing Mission (AOM)

- Meteorology
- Space Weather
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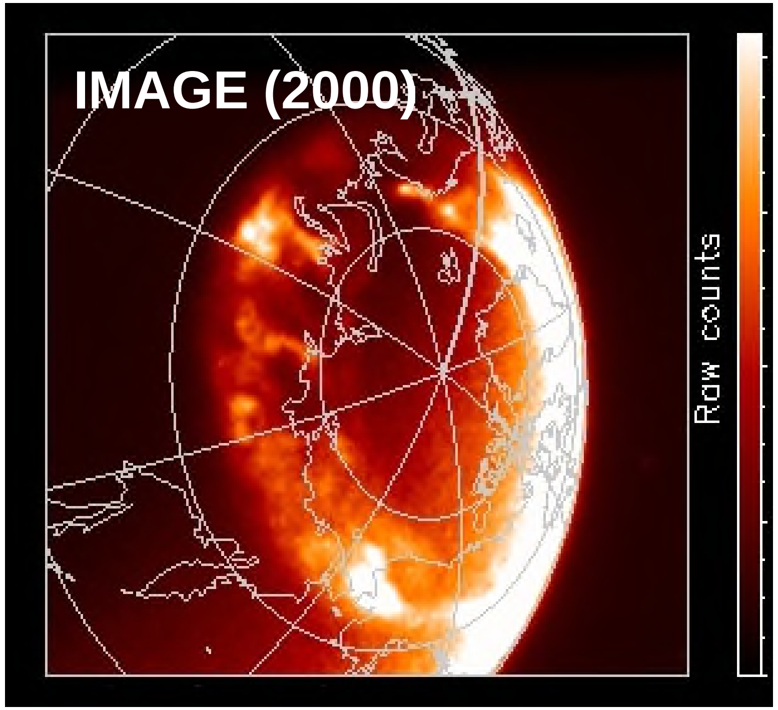
Space Weather Instrument Suite

- NOAA and NASA's Heliophysics Division have an interest in space weather observations from AOM
- AOM's northern-focused orbit provides a unique vantage point for space weather observations
- The following SW instrument suite is proposed:
  - UV-visible Auroral Imager ~ 61 kg
  - In situ particle analyzers ~30 kg
  - Magnetometer ~3 kg
- Considered as a joint NOAA-NASA contribution to AOM
- Space weather is outside of ECCC's mandate, but currently clarifying the value of the proposed observations to other Canadian government departments, especially Natural Resources Canada (NRCan), as well as science community



Arctic Observing Mission (AOM)

- Meteorology
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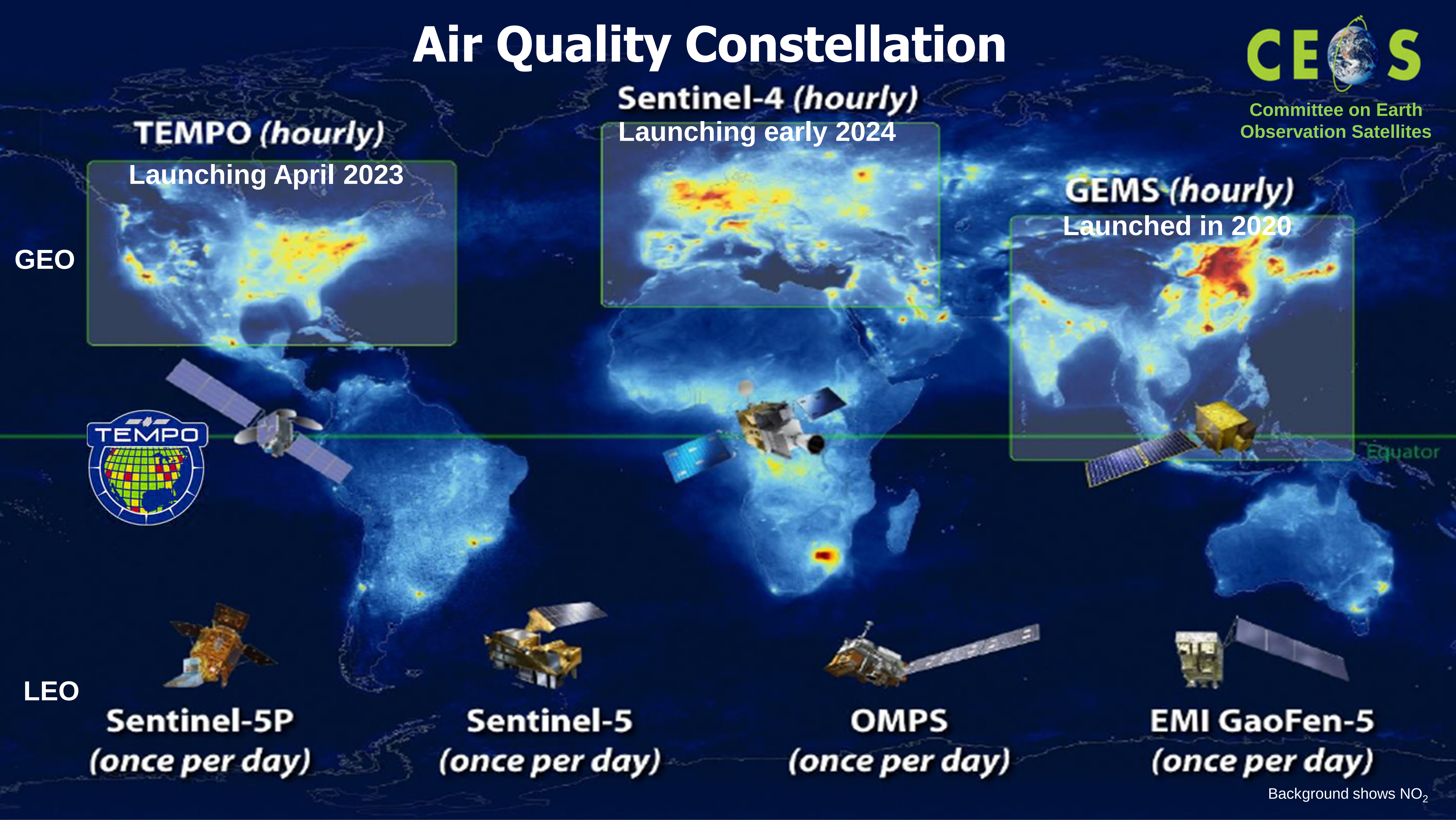
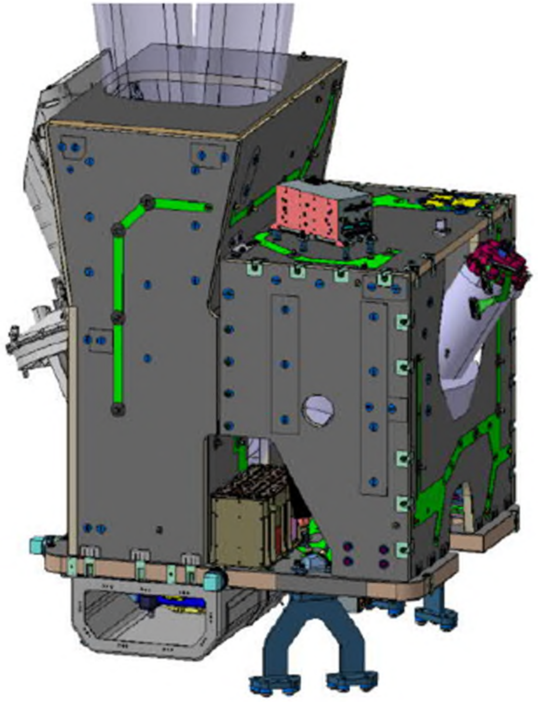
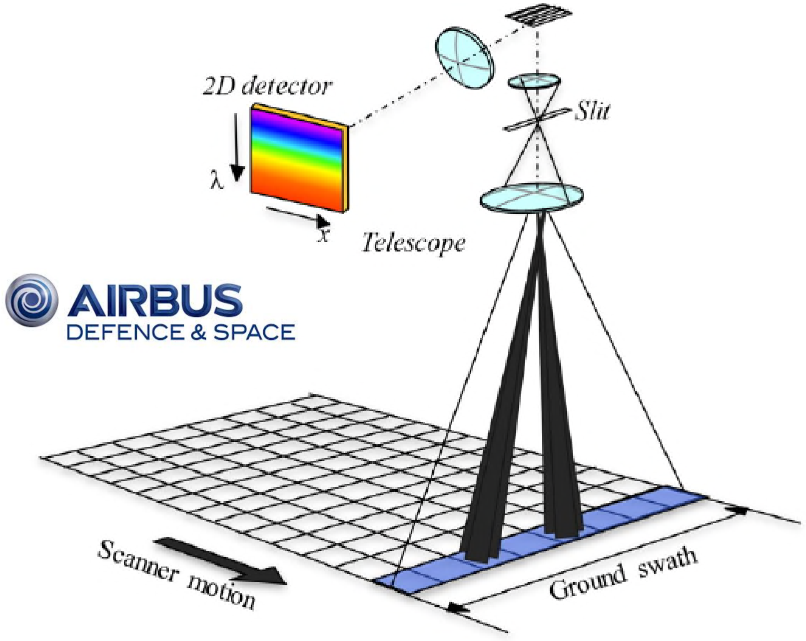

Air Quality Constellation
CEOS
Committee on Earth Observation Satellites
TEMPO (hourly)
Launching April 2023
Sentinel-4 (hourly)
Launching early 2024
GEMS (hourly)
Launched in 2020
GEO
TEMPO
Equator
LEO
Sentinel-5P
(once per day)
Sentinel-5
(once per day)
OMPS
(once per day)
EMI GaoFen-5
(once per day)
Background shows NO_2

AOM Air Quality Instrument

"Full Capability AQ instrument":
Similar design to Copernicus/ESA
Sentinel-4 GEO AQ instrument

- Pushbroom scanning
- 4x4 km^2 instead of 8x8 km^2
- 290-780 nm
- 0.25 nm spectral sampling
- 0.8 nm spectral resolution
- Addition of line imager for sub-pixel (500x500 m^2) cloud and aerosol data
- Mass 182 kg (including 15% margin)





- Pre-formulation study aims for a "Reduced Capability AQ instrument" continuing with dispersive spectrometer technology, 100 kg maximum, UV-vis observations (~280-540 nm) for NO_2 (top priority for synergy with CO_2), O_3 (next priority), some capability for SO_2, BrO, HCHO, ClOClO
- Combined with aerosol information from ABI, would support emission monitoring, AQ forecasts and science applications

A new industry team is to be determined through a competitive process for AOM pre-formulation study.

Arctic Observing Mission (AOM)

- Meteorology
- Space Weather
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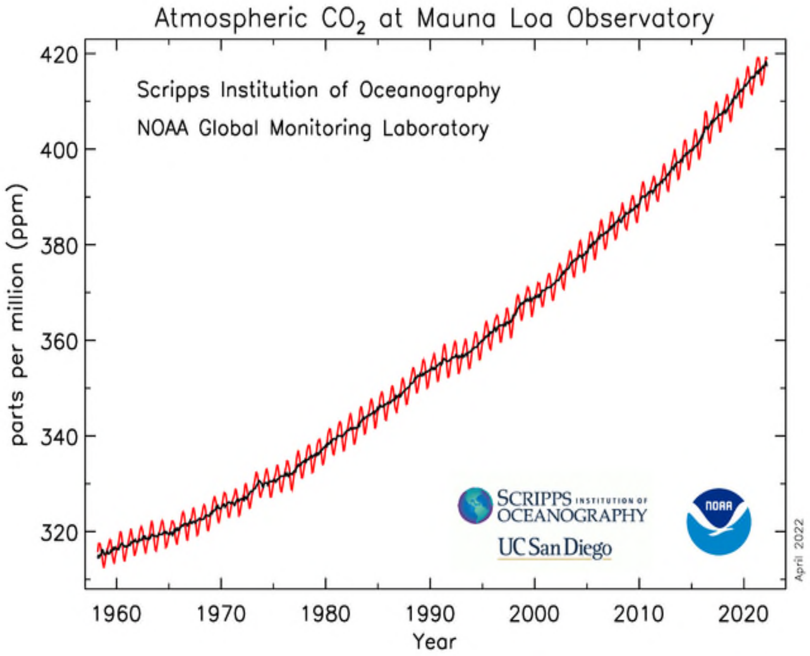
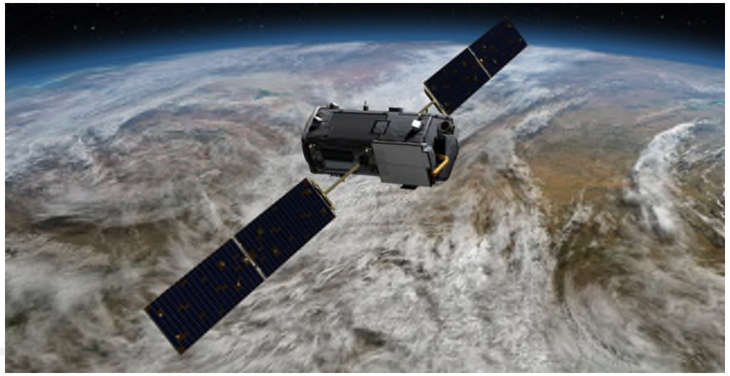
Why measure GHGs?

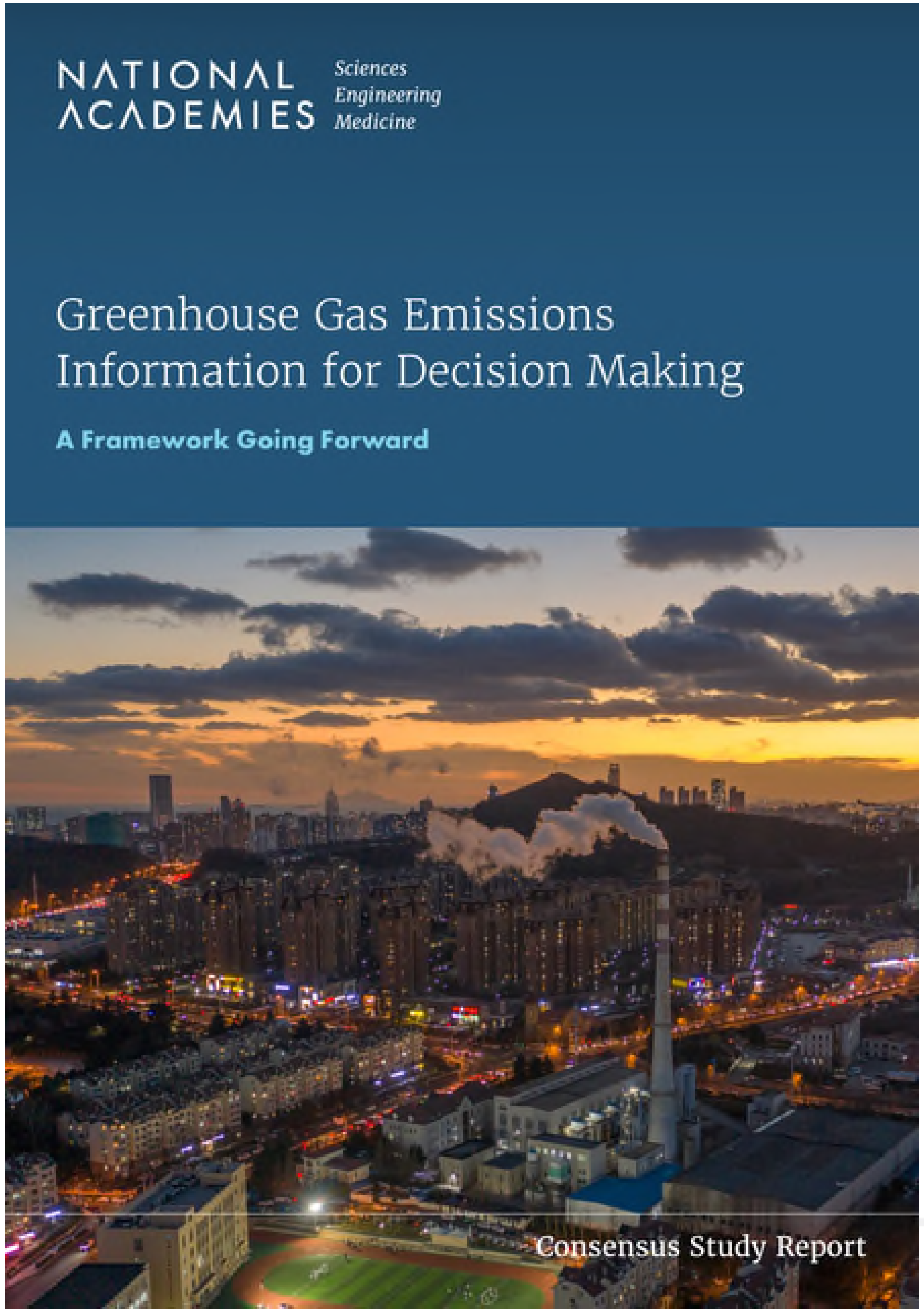
- Measurements of the atmospheric distributions of CO_2 and CH_4 can be used with atmospheric transport data to quantify surface emissions (and sinks) of these GHGs as pioneered with ground-based in situ GHG measurements from a relatively sparse network

- Satellites cannot match in situ accuracy and precision, but can give orders of magnitude more spatial coverage and the ability to quantify CO_2 and CH_4 emissions from space has been demonstrated at a range of spatial scales

- CO_2 and CH_4 observations have improve our scientific understanding of the carbon cycle, which enable better predictions of future climate and the potential for monitoring and verifying emissions to support emission reduction efforts and climate mitigation action

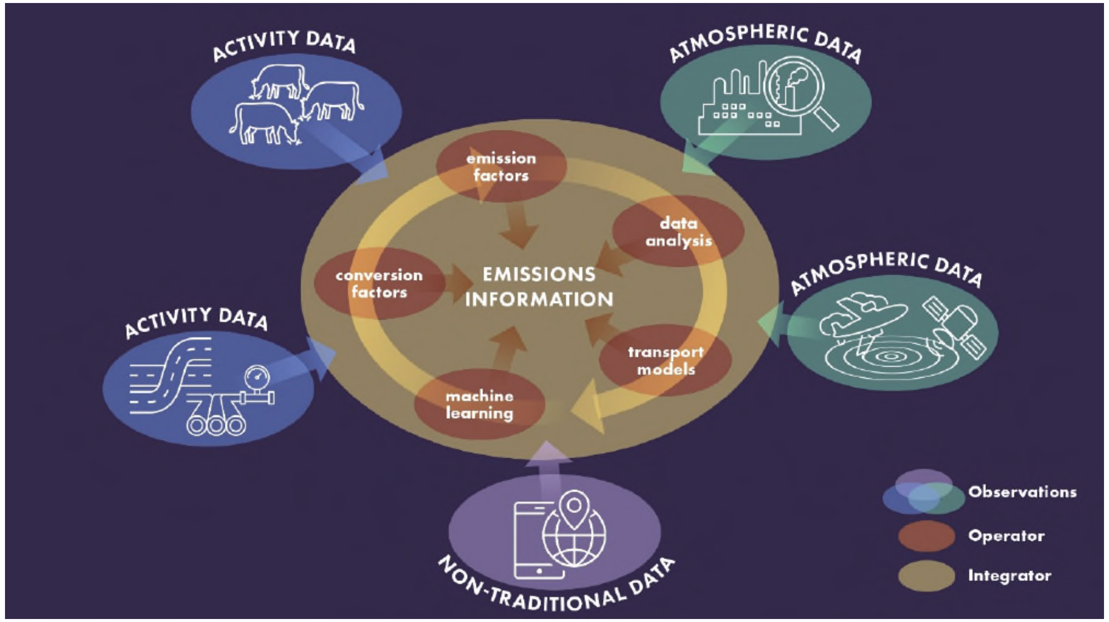






US National Academies recommends a “Hybrid” approach to greenhouse gas emission information for decision making.

A “Hybrid” approach combines traditional activity-based methods of GHG emission calculation with atmospheric measurements, including satellite CO_2 and CH_4 observations.



Committee on Earth Observation Satellites (CEOS), Coordination Group for Meteorological Satellites (CGMS) and World Meteorological Organization (WMO) have active interest in space-based capabilities for observing CO_2 and CH_4.

Noted in NOAA's Climate Ready Nation Deliverables

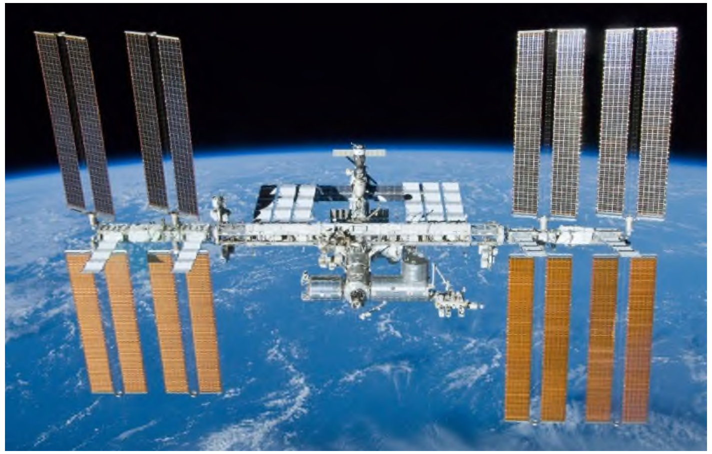
FIVE-YEAR OUTPUTS: MONITORING AND MODELING FOR CLIMATE CHANGE MITIGATION

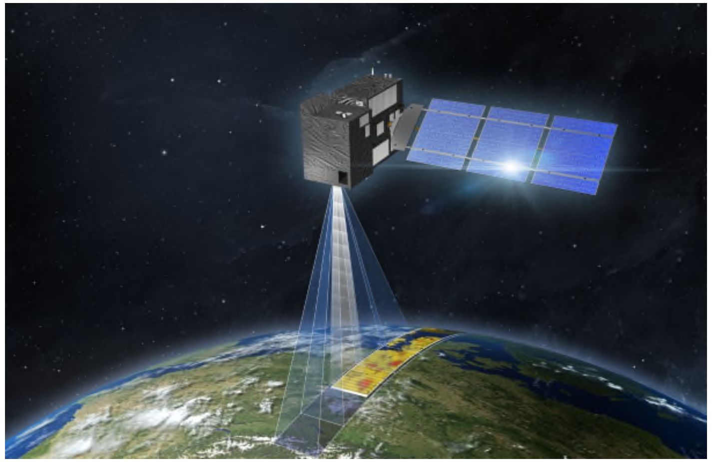
Area	Output
Greenhouse Gas observation and Modeling Capabilities	1. Develop GHG observation and modeling capabilities with NOAA domestic and international partners to reliably track changes in natural and human-made GHG emissions and sinks over time and at local, regional, continental, and global scales. Ensure the quality and necessary scientific stewardship of in situ and remotely sensed data sets from NOAA and partner observing systems.
Models, Tools, and Products for Climate Mitigation	2. Be a reliable provider of models, tools and products for decision makers to determine the feasibility of achieving climate mitigation targets, taking into account anthropogenic emissions, ocean fluxes, and feedbacks in the earth system, and to evaluate the broader climate implications of various mitigation measures.
Quantification of Key Emission Sources Products and Services	3. Deliver products and services that improve quantification of key emission sources to help decision makers at various scales identify important mitigation opportunities. Such sources include GHG emissions from urban sources, from the land-use and agricultural sectors, methane leaks from industry, and small quantities of potent GHG emissions from niche applications.

Key CO_2 and CH_4 Satellite Missions

- NASA OCO-2 (CO_2 launched 2014), OCO-3 on ISS (CO_2 launched in 2019), EMIT on ISS (CH_4) …
- Japan's GOSAT/GOSAT-2, future GOSAT-GW
- Copernicus/ESA: Sentinel-5P TROPOMI (CH_4)
- NASA commercial data purchase of GHGSat (CH_4)

- **Future**: MethaneSat, MicroCarb (CNES), CarbonMapper, upcoming NASA Earth System Explorer (ESE), Copernicus CO2M satellites to launch in 2026-2027 ….





GOSAT OCO-2 OCO-3 GHGSat MICROCARB MethaneSAT CARBON MAPPER CO2M Copernicus Anthropogenic Carbon Dioxide Monitoring

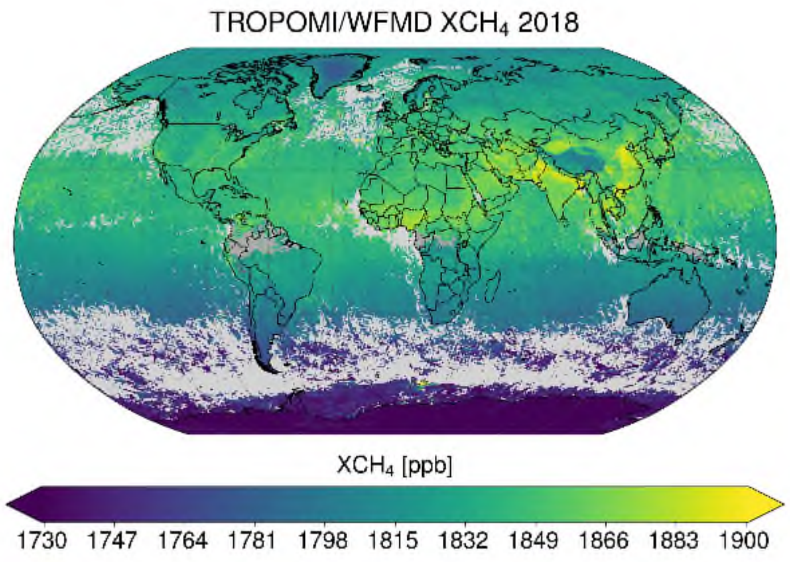
A CONSTELLATION ARCHITECTURE FOR MONITORING CARBON DIOXIDE AND METHANE FROM SPACE

6.1 A CO_2/CH_4 constellation architecture with LEO, GEO and HEO elements

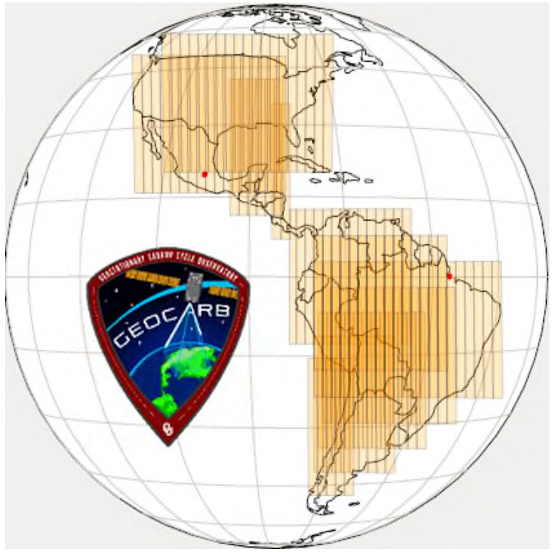
A constellation of CO_2/CH_4 satellites that fully exploits the assets of the LEO, GEO, and HEO vantage points will be needed to meet the demanding GCOS requirements for precision, accuracy, spatial and temporal resolution and coverage summarized in Table 6.1. The following sub-sections describe a point design for a NIR/SWIR constellation architecture that addresses these requirements over continents, while providing somewhat lower resolution and coverage over the ocean.

[Crisp et al. (2018) CEOS White Paper]

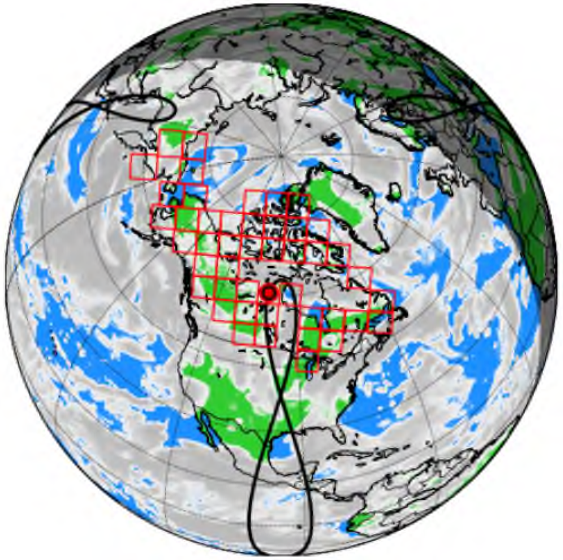
Low Earth Orbit (LEO)



Geostationary Orbit (GEO)



Highly Elliptical Orbit (HEO)

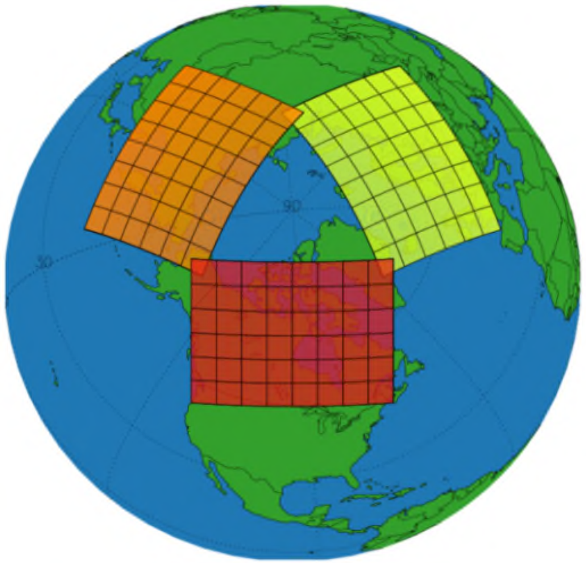


- **Low Earth Orbit (LEO):** Near polar-orbit, global sampling, but low temporal revisit rates
- **Geostationary Orbit (GEO):** Equatorial orbit, rapid revisit rates, but limited to ~60°S-60°N
- **Highly Elliptical Orbit (HEO):** Can be oriented to give quasi-geostationary observations over polar regions

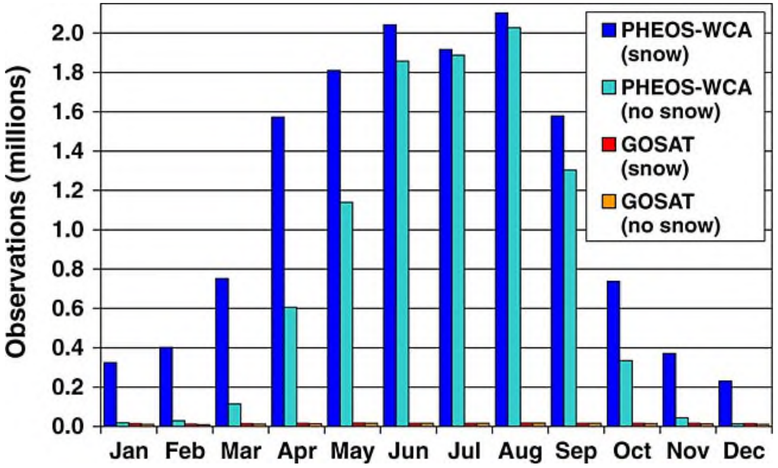
Past CO_2 Observing System Simulation Experiment (OSSE)

- Simulations compared the potential information from a proposed HEO mission vs. GOSAT for constraining Arctic and Boreal CO_2 surface fluxes using synthetic CO_2 observations.
- ~40-70 kg Imaging Fourier Transform Spectrometer (IFTS) on Polar Communications & Weather (PCW) mission

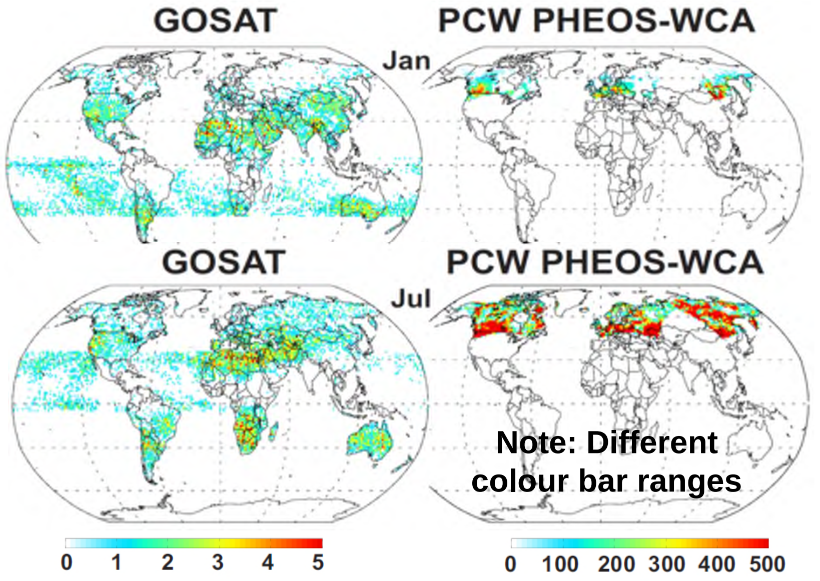
HEO Fields of Regard



Total observations per month



Number of observations per 1°x1° per month



GOSAT mean simulated obs per month: 14973
NIES v2, 1st year of mission: 14393

*Precision of observations over snow degraded by a factor of 2

- Proposed HEO mission could give flux uncertainty *reductions* relative to GOSAT of ~30% annually and ~45% in summer
- A new CO_2 OSSE is underway with observing characteristics under consideration for AIM-North/AOM

Nassar, Sioris, Jones, McConnell (2014), Satellite observations of CO_2 from a highly elliptical orbit for studies of the Arctic and boreal carbon cycle, *J. Geophys. Res.* 119, 2654–2673, https://doi:10.1002/2013JD020337.

GHG Imaging FTS

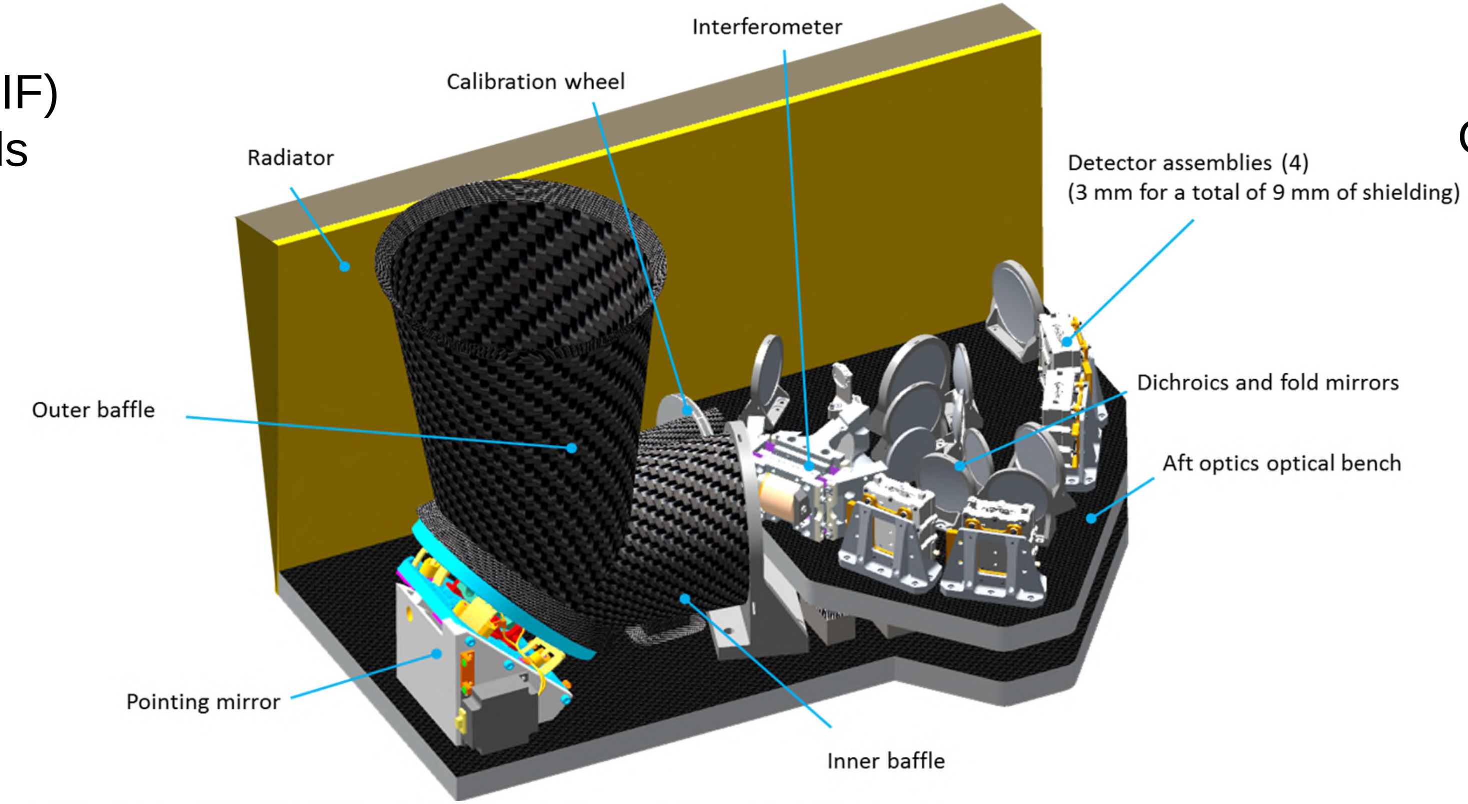
Selected as baseline for remainder of Phase 0 for competitive precision performance, superior cloud avoidance potential.

ABB

Similar species (CO_2, CH_4, CO, SIF) and spectral bands to GeoCarb:

0.758-0772 μm,
1.598-1.618 μm
2.042-2.079 μm
2.301-2.380 μm

Synergy with AQ NO_2 observations



FTS systems on CSA SCISAT/ACE, China's AIUS on Gaofeng-5

Interferometers: JAXA GOSAT/GOSAT-2, NOAA CrIS series

Mechanical Layout (covers removed)

Mass = 164 kg (including ~30% margin)

Precision achieved based on current IFTS and grating spectrometer design options for a reference scene (SZA = 45°, VZA = 0.1°, AOD = 0.1 and forest albedo).

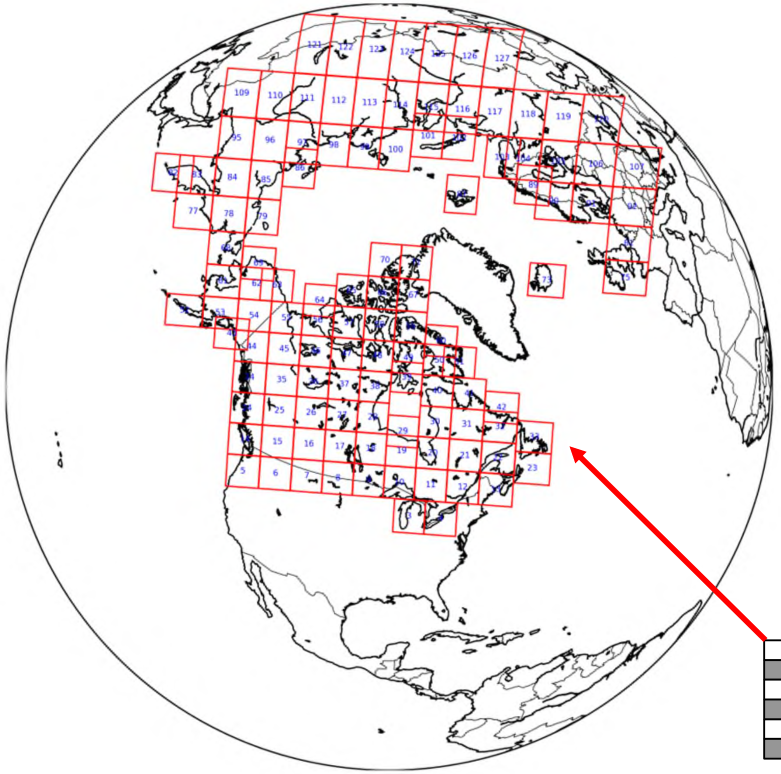
(%)	XCH_4	XCO	XCO_2
Grating	0.53	7.63	0.40
FTS	0.62	8.56	0.42

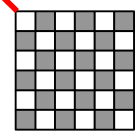
A new industry team is to be determined through a competitive process for AOM pre-formulation study.

Planned AOM GHG Observing Approach

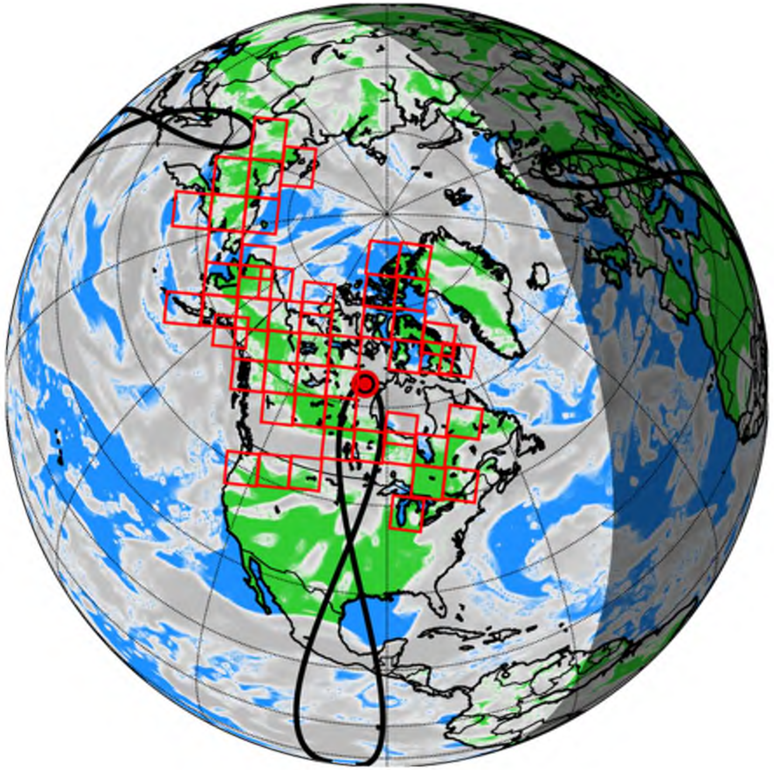
- About 70% of Earth is covered by clouds at any moment, resulting in loss of most observations with standard pointing
- *Intelligent Pointing* building off pioneering approach of GOSAT-2 (Japan) may be more effective from GEO/HEO than LEO
- With real-time cloud information (such as a cloud mask from ABI), 128x128 pixel Field-of-View (FOV) could be pointed at 54 best locations per hour, resulting in hourly revisit during daylight for cloud-free land areas north of 45°N for most of the year

Potential FOV pointing locations





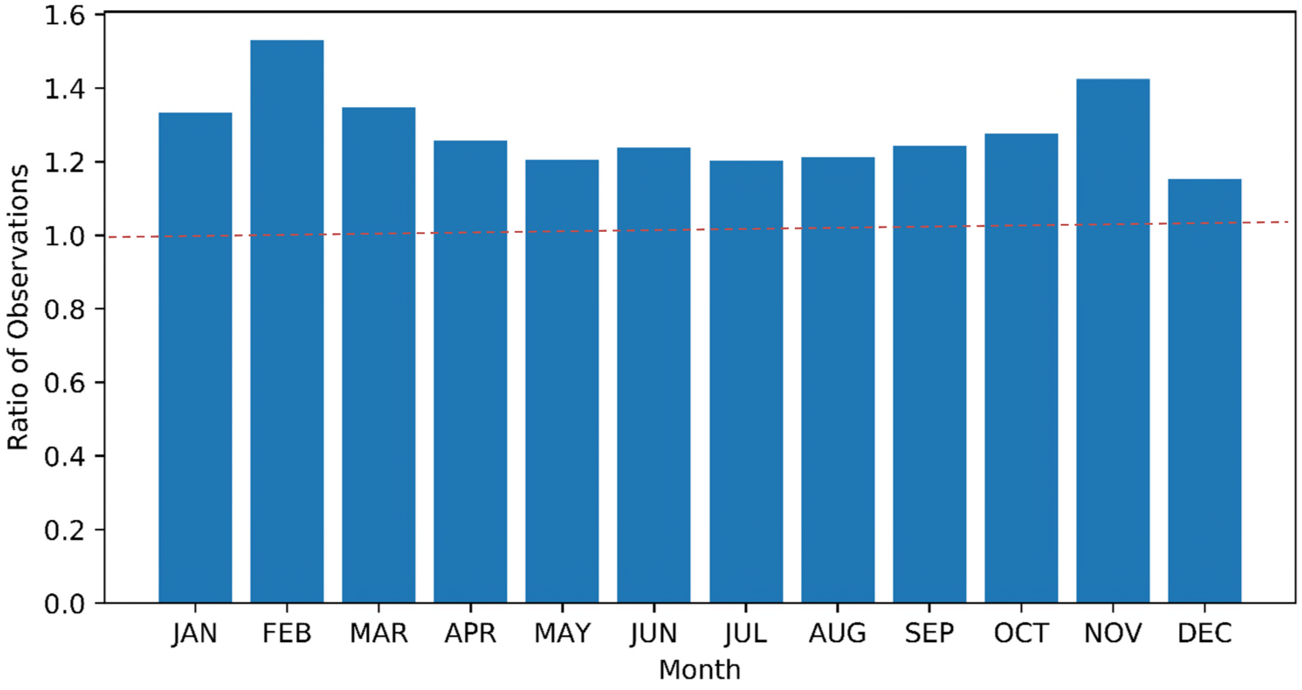
FOV Selections

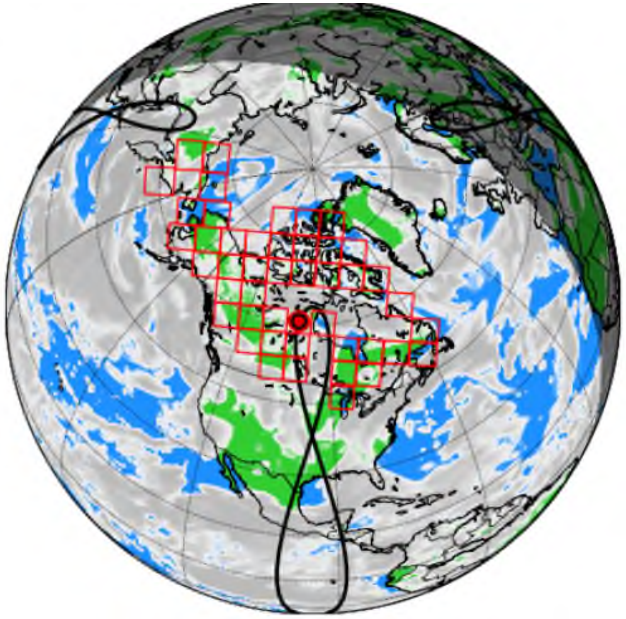


Potential FOV locations from 95°W apogee with a 128x128 pixel FOV and 4x4 km^2 pixels (left).
NASA MERRA-2 cloud cover for 2015-06-01 17:30 UT and selected FOV positions. Satellite and TAP orbit track also shown (right).

Intelligent Pointing Results

Monthly ratio of cloud-free observations: IFTS to Dispersive





IFTS
128x128 pixels, 60 seconds per stare,
54 stares/hour, ~6 seconds repointing

Dispersive
480 pixels per scan, 36 scans/minute,
~6 seconds repointing time

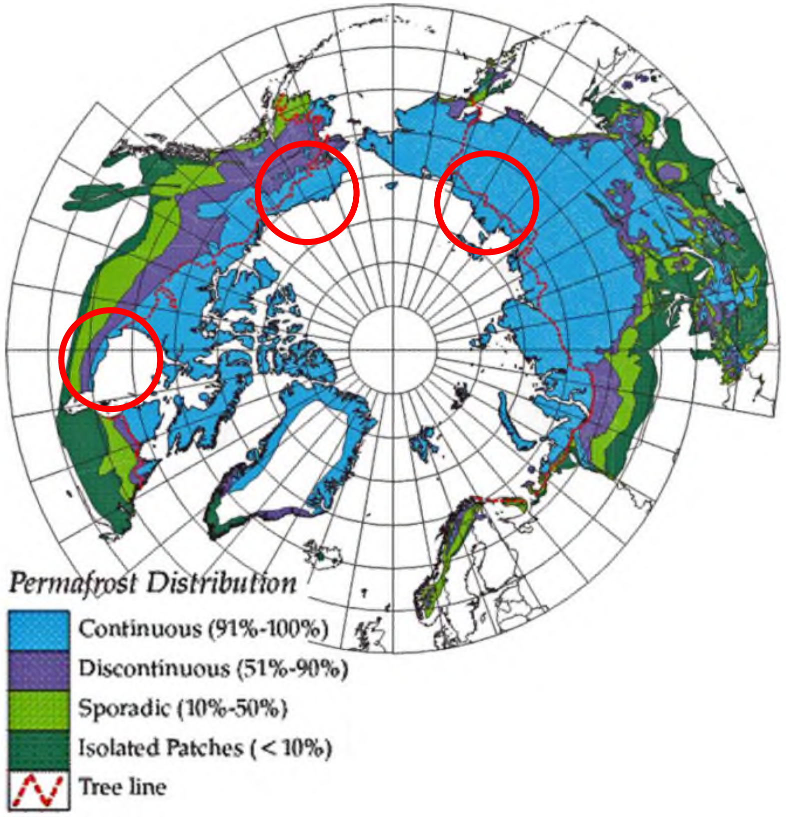
Even with ~5% more raw dispersive spectrometer observations, the IFTS obtains 20-55% more successful cloud-free observations per month with intelligent pointing due to the 1:1 aspect ratio, which is better for viewing irregular regions like coasts and the gaps between clouds.

AOM & CO2M Observing System Simulation Experiment (OSSE)

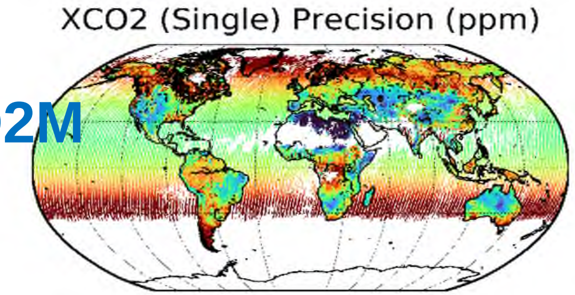
Compares XCO_2 from AOM (2 HEO satellites) and CO_2M (3 LEO satellites) to understand differences in the ability to quantify northern biospheric CO_2 fluxes including CO_2 emissions from permafrost thaw

Method:

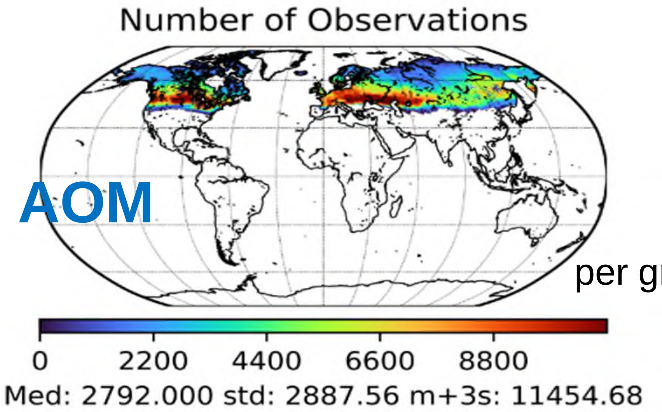
– Generate 18-mon synthetic observation locations and times for each mission (AOM and CO_2M) considering orbits + instrument characteristics
– Filter raw observation locations for clouds, AOD, albedo, viewing/sun geometry
– Use EC-CAS model simulation with permafrost CO_2 emissions for XCO_2 and perturb 'true' XCO_2 with realistic random errors and bias for each mission
– Assimilate synthetic observations in global (2°x2.5°) GEOS-Chem 4Dvar separately for each mission, then combined, to estimate 1-yr land biosphere flux
– Assimilate synthetic AOM/CO2M observations in high resolution (0.25˚x0.3125˚) North American system (10-day period) without fixed diurnal cycle



CO2M

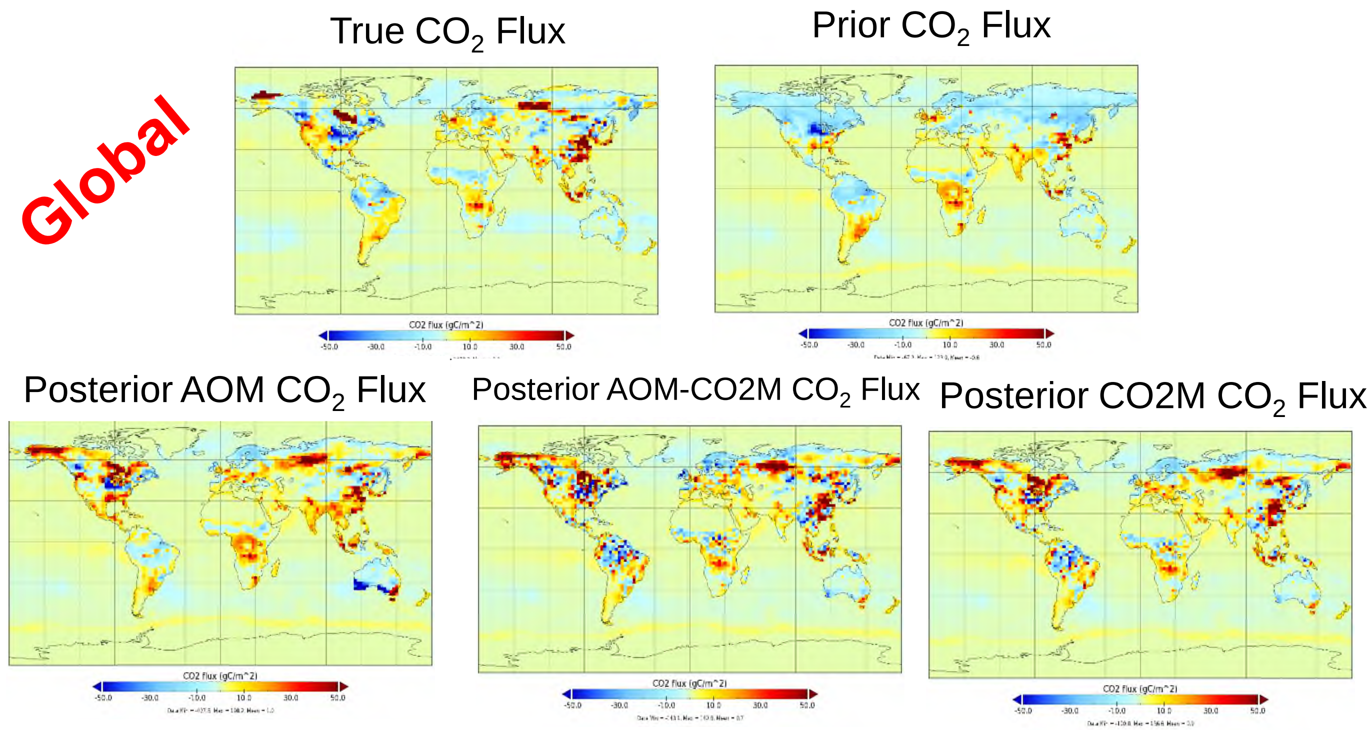


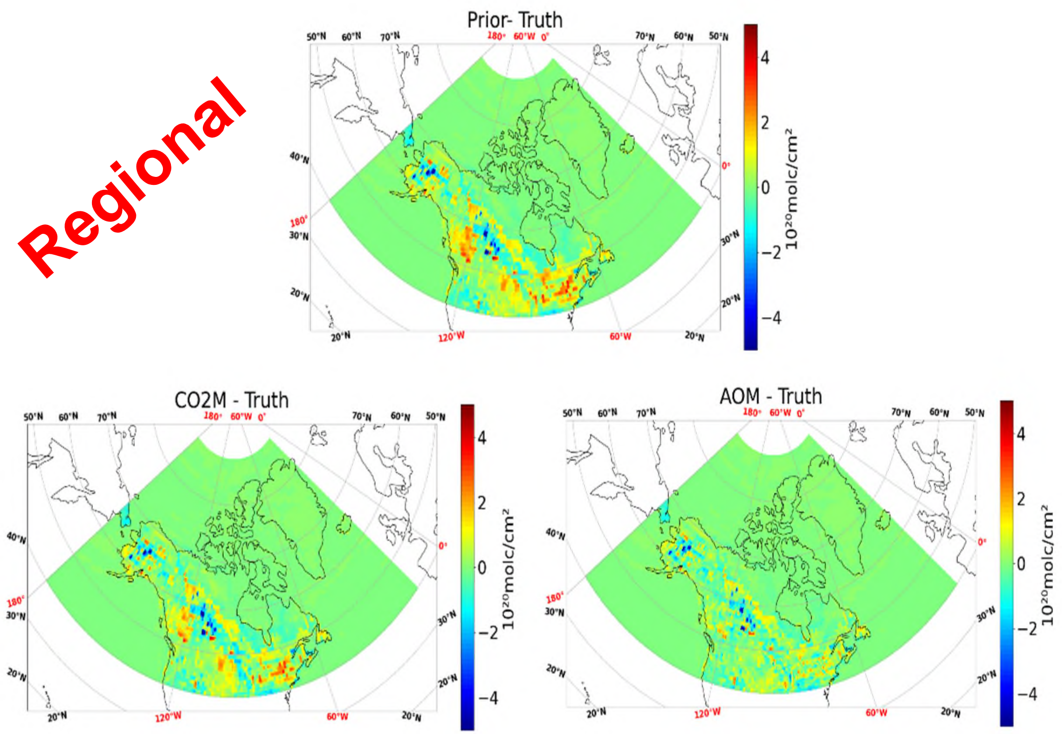
AOM



per grid box (0.25°x0.3125°)

AOM and CO2M CO_2 OSSE Results





AOM and CO2M have complementary capabilities for quantification of northern high latitude CO_2 fluxes.
Combining the data from these missions will lead to the best flux estimates.
Expect that detection and quantification of permafrost CO_2 emissions to be more challenging than CH_4.

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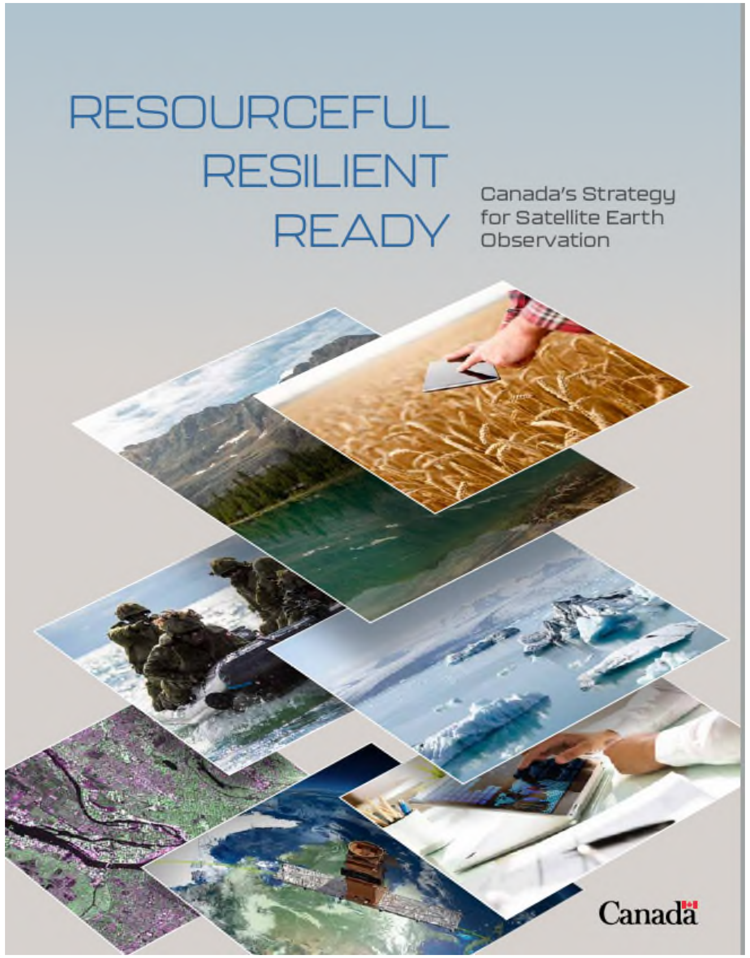
Jinwoong Kim, Ray Nassar, Alex Fogal, Cameron MacDonald,
Anthony Girmenia, Safwan Khan

Environment and Climate Change Canada
Environnement et Changement climatique Canada

UNIVERSITY OF WATERLOO

Canada's Strategy for Satellite Earth Observation



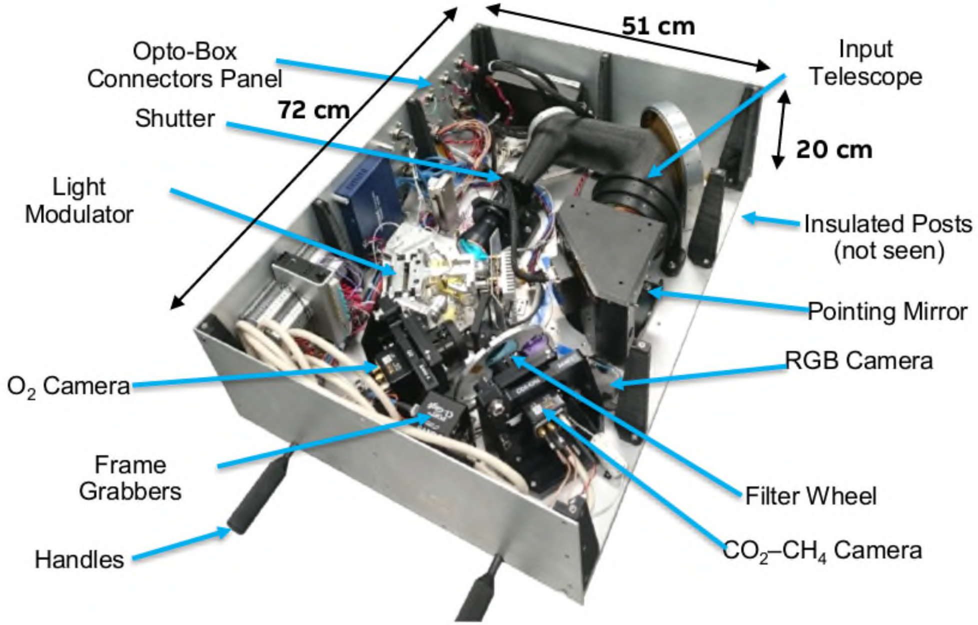
High-altitude balloon prior to launch.
Credit: ECCC-CSA

SATELLITE EO IN ACTION:
Testing New Technology for Monitoring Greenhouse Gases from Space

Canadian industry leads the world in Fourier Transform Spectrometer (FTS) technology and is currently advancing it to better observe atmospheric gases from space. FTS enables satellite imaging of critical gases such as carbon dioxide (CO_2) and methane (CH_4) that are leading causes of climate change. The technology also supports the surveillance of other important greenhouse gas emissions from sources such as permafrost thaw and forest fires in a warming climate. Canada is targeting application of this new technology as part of future missions, particularly to monitor the Arctic more closely. In preparation, the GC, along with industry and academia, are working together to test prototypes using high-altitude balloons. These high-altitude balloon experiments allow scientists to test how the instrument operates in the cold, low-pressure environment of the stratosphere, a precursor to the instrument one day operating in space.

IFTS Stratospheric Balloon Campaign

- Imaging FTS CO_2 & CH_4 balloon measurements over boreal forest (CSA-CNES facility, Timmins, ON) made August 22, 2022 to demonstrate technology for AOM
- Nadir viewing from 37 km altitude during 13 h flight, (daylight & night) with 4 hours of adequate SZA
- 56x56 array of 8.5x8.5 m^2 pixels, integration t =100 s
- 2 Bruker EM27/Sun ground-based FTSs (F. Vogel, ECCC) to validate the IFTS observations
- Almost had coincident CoMet 2.0 Arctic measurements (MAMAP2D and other GHG instruments)
- Currently re-processing Level 2 (XCO_2, XCH_4)



Environment and Climate Change Canada

Environnement et Changement climatique Canada

Next Steps for AOM

- Conclude some current studies: Analysis of balloon IFTS data, Socio-economic benefits, Intelligent Pointing Study, CO_2 OSSE, etc.
- AOM Mission Design Contract RFP closes April 6, followed by evaluation, selection, kick-off of a new industry contract for 18-month pre-formulation study on the refinement of the mission/instrument design and costing
- Continuation of CO_2:NO_2 study, radiation environment studies, parallel technology development (IFTS, pointing mechanism, focal plane arrays …) and clarifying roles and contributions from prospective international partners
- Canadian funding request in late 2024, with expected spring 2025 decision
- If successful, AOM implementation will begin, aim for 2034 launch, 10-year mission!

Summary, Conclusions, Partnership

- Arctic and northern latitudes is a region of Earth undergoing rapid change and is a priority region for Canada satellite Earth observation
- AOM is an innovative HEO mission concept for meteorology, GHGs, air quality and space weather with a strong focus on the North
- AOM is envisioned as a Canadian-led international mission in which partnership contributions are essential to its success
- Recent progress on clarifying and solidifying intended NOAA and NASA contributions is a positive step forward, while we also welcome further involvement from international partners on other components of AOM

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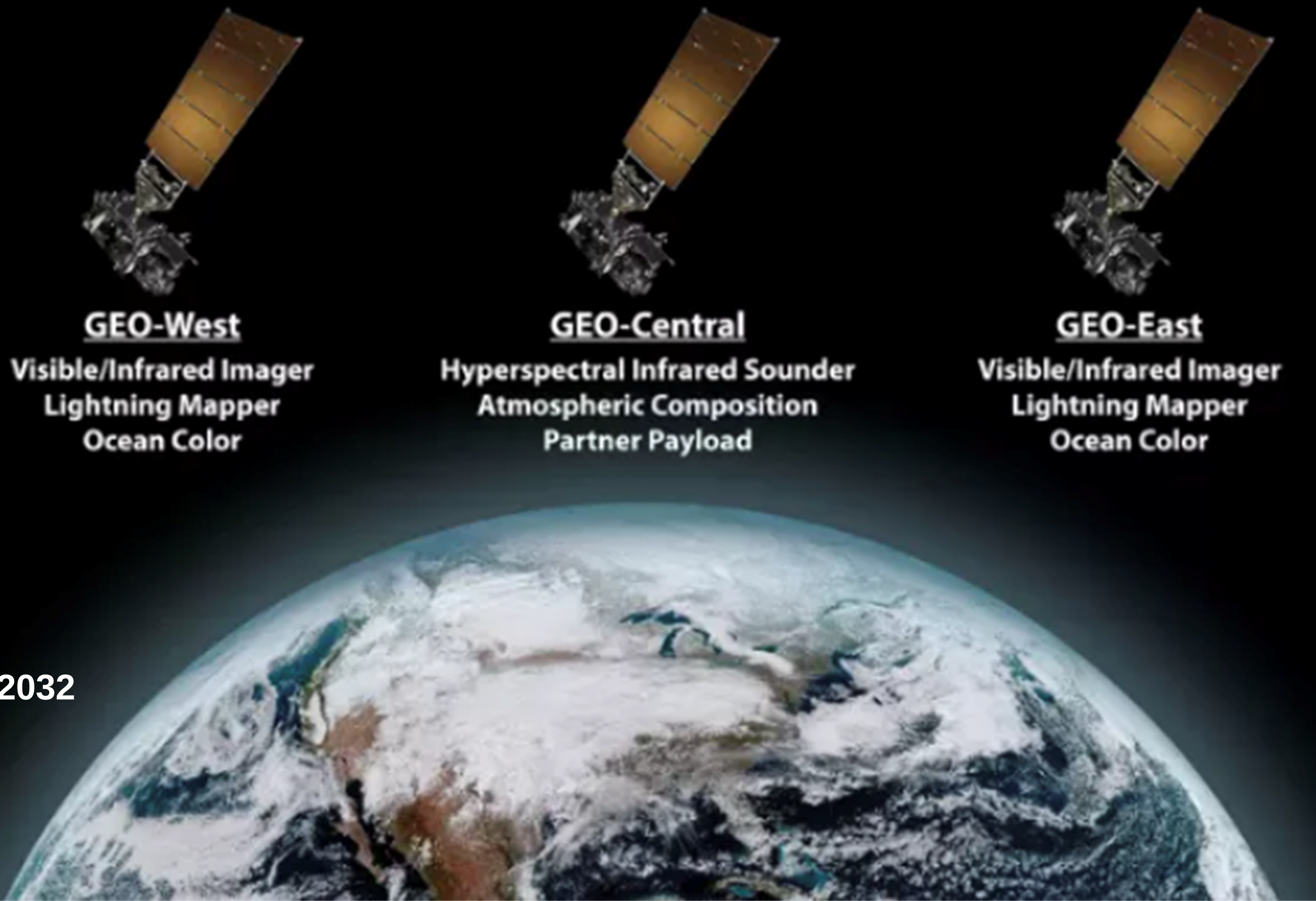
Thank You

Extra Slide

GeoXO Constellation

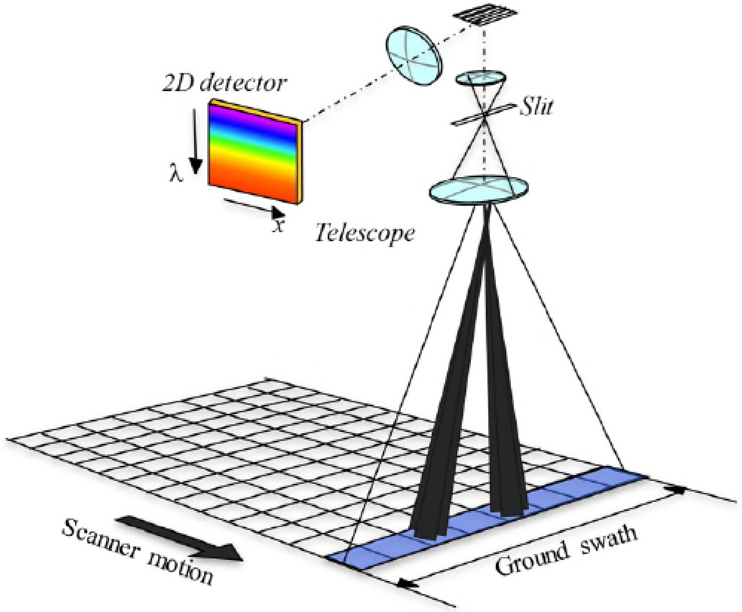


First launch in 2032

Different Scanning Approaches

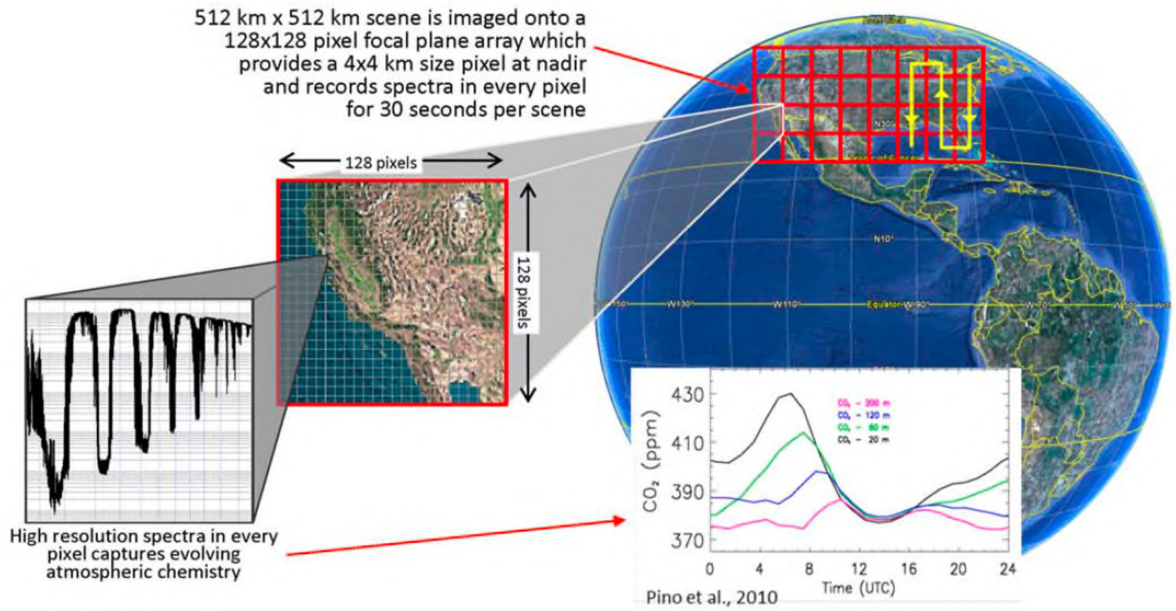
Extra Slide

Dispersive: Push-broom Scanning



Credit: Airbus

IFTS: Step-and-Stare Scanning



Xi et al. (2015), GEO-FTS concept, AMT, 8, 4817
doi:10.5194/amt-8-4817-2015

Extra Slide

remote sensing

MDPI

Article

Pixel Size and Revisit Rate Requirements for Monitoring Power Plant CO_2 Emissions from Space

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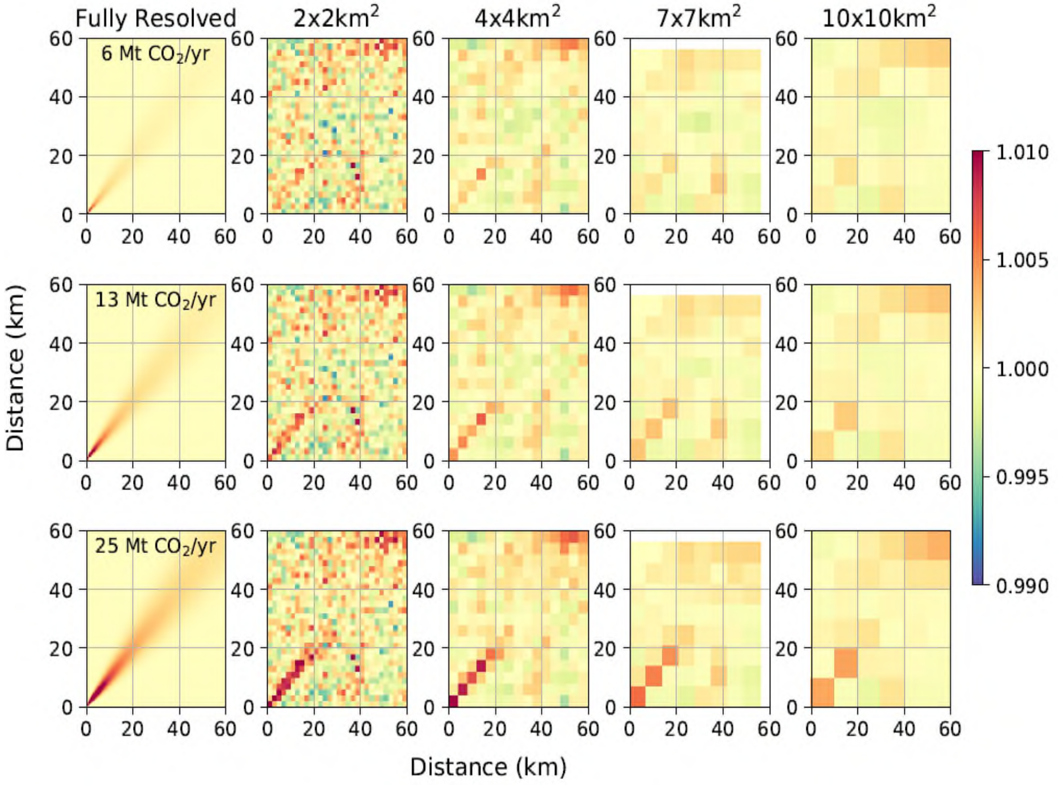
Received: 31 May 2019; Accepted: 5 July 2019; Published: 6 July 2019

check for updates

Abstract: The observational requirements for space-based quantification of anthropogenic CO_2 emissions are of interest to space agencies and related organizations that may contribute to a possible satellite constellation to support emission monitoring in the future. We assess two key observing characteristics for space-based monitoring of CO_2 emissions: pixel size and revisit rate, and we



- ≤ 4x4 km^2 is good target pixel size for power plants (consistent with Broquet et al. AMT 2018, for urban areas)
- To derive policy-relevant annual emissions for individual power plants, multiple revisits are required to adequately sample and account for the temporal variability throughout the year
- Required number of revisits depends on accuracy of estimation from single view and target annual accuracy: e.g. if one view gives 10% uncertainty on daily emissions, estimating annual emissions at 10% requires 41 revisits

Extra Slide

Canada's Contribution to International Constellations for Greenhouse Gases, Air Quality and Weather

- GHGs: Copernicus and CEOS vision for GHGs is LEO constellation in near term followed by GEO+HEO later
- AQ: GEO + LEO constellation will be in place in early 2020s, but extending coverage to north via HEO needed
- Weather: WMO & CGMS vision includes HEO for northern coverage in an integrated global observing system
- Canada can address the northern gap across these disciplines by leading the Arctic Observing Mission (AOM)

Greenhouse Gases

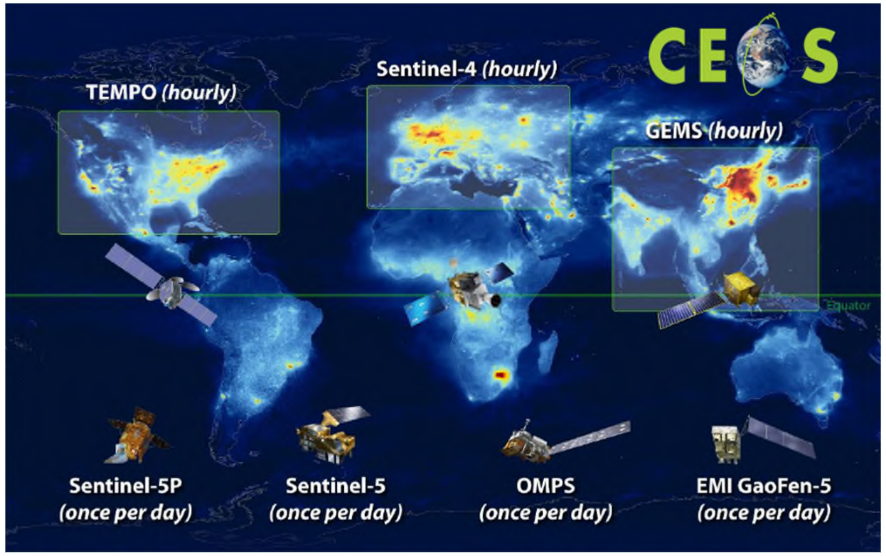
CEOS Committee on Earth Observation Satellites

A CONSTELLATION ARCHITECTURE FOR MONITORING CARBON DIOXIDE AND METHANE FROM SPACE

6.1 A CO_2/CH_4 constellation architecture with LEO, GEO and HEO elements

A constellation of CO_2/CH_4 satellites that fully exploits the assets of the LEO, GEO, and HEO vantage points will be needed to meet the demanding GCOS requirements for precision, accuracy, spatial and temporal resolution and coverage summarized in Table 6.1. The following sub-sections describe a point design for a NIR/SWIR constellation architecture that addresses these requirements over continents, while providing somewhat lower resolution and coverage over the ocean. One or more of the LEO platforms would have to carry active CO_2 and CH_4 Lidars to provide useful constraints on XCO_2 and XCH_4 over the nighttime hemisphere. Lidar measurements could also provide global constraints on systematic biases in passive SWIR observations associated with variations in the solar illumination and viewing geometry.

Air Quality



Weather

WORLD METEOROLOGICAL ORGANIZATION

CGMS